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FINAL REPORT

Spot Size Reduction Study For High Resolution Radar Recorder

14 FEBRUARY 1964

Prepared for
WESTINGHOUSE ELECTRIC CORPORATION
BALTIMORE, MARYLAND
Contract No. 86J-30-53155-0G

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LEXINGTON 73, MASSACHUSETTS

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FIGURES

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1. INTRODUCTION

The Radar Data Recorder program involved the design and fabrication of an equipment item for use in a radar system. The performance requirements were sufficiently stringent as to require state-of-the-art advances in many areas of the design. Therefore, a study program for attacking problems of system performance was initiated at the start of, and ran concurrently with, the design and fabrication program. While the initial goal of this study was the reduction of CRT spot size for the purpose of increased system resolution, work was performed (with Westinghouse approval) upon other factors affecting system resolution. Since this work also had the effect of improving system resolution, as any reduction in spot size would have had, the heading "Spot Size Reduction Study" has been retained.

Early in the study the resolution of the film output was determined to be dependent not only on spot size but on such other factors as (1) the effects of electronic noise, hum, and jitter on the CRT scan and on the sensitometry of the recording film, (2) the constancy of the film motion at the imaging slit, and (3) mechanical noise and vibration originating within the recorder or introduced by sources external to it.

Much time was spent in the design of auxiliary testing equipment. A swept frequency test oscillator was developed, and proved to be a valuable tool. Techniques for measuring resolution and for determining the smoothness of film motion and the effects of noise and jitter were developed which proved to be useful in improving the performance of the recorder. For a detailed description of these and other test devices used, see Section 5 of this report.

The project procured the recording CRT's from Westinghouse, Elmira, New York. However, tubes of different design—in particular, a reflex focusing tube developed by General Electric—were studied for possible contributions they might make to improve resolution.

Several equipments for test purposes were constructed in breadboard configuration. Test equipment for flight line testing was delivered to Westinghouse, Baltimore, as part of the work done under the Spot Size Reduction program.

Attention was given to various methods of determining the resolution obtained in the recording process. Since the system performance is dependent on integrating the information on the recorder output film, ordinary methods of evaluation were found to be unsatisfactory, and methods using the transform properties of the diffraction pattern produced by the recorded film were studied. As a result of this study, a method of evaluating the efficiency of the recorder in recording high frequencies was developed.

The work directed towards improving the resolution of the recorder system has resulted in a 100 percent improvement in the effective resolution. Measurements of resolution in the early phase of the program indicated 500-cps response at 3 percent for the center of the optical axis; 1,000 cycles per inch at the center of the field is currently being obtained. This response was accomplished largely by the reduction of external disturbances, such as vibration and the effects of moving magnetic fields.

Although further improvements in recorder resolution are expected from the use of new CRT's having spot sizes of 0.3 mils (the spot size of present tubes is of the order of 0.7 mils), further refinements must be achieved in techniques for reducing the effects of the environment in which the tubes are operated.

2. RECORDER RESOLUTION

In this section, factors are discussed which were involved in photographing the CRT display. Aspects of the system performance which are mentioned here include lens-film resolution, linearity of transfer, signal-to-noise ratios, and stability under environmental conditions.

2.1 LENS-FILM RESOLUTION

In the Radar Data Recorder system, we were mainly concerned with resolution. The lenses used in the recorder are Wollensak 6 3/8-inch (162-mm), f/2, Raptar special input lenses used a a 1:1 conjugate ratio. We have demonstrated a limiting resolution for the recorder of 1,000 cycles per inch (approximately 3 percent response). This is corroborated theoretically by Fig. 2-1, which shows the spatial frequency modulation transfer for the Wollensak lens, Plus-X Aerographic film, a 0.8-mil spot, and the combined result. A limiting response of 3 percent or 1,000 cycles per inch is indicated, and agrees with experimental tests on the recording system. The spatial frequency characteristic for a 0.5-mil spot is also plotted for reference.

In Fig. 2-2 the same calculation is made for a 0.5-mil spot, using the same lens and film as for the previous calculations. Limiting resolution on axis is shown to be 1,600 cycles per inch, or 63 lines per millimeter at the 3 percent cutoff point. It is obvious that, other parameters constant, considerable improvement will be had by obtaining a CRT with smaller spot size.

Improvement may also be sought in terms of better film emulsions. The present use of Plus-X is based largely on convenience, since it is easily obtainable in the 9 1/2-inch widths. Development of other emulsions may bring improvements. However, if the Plus-X film achieved 100 percent transfer at 400 cycles per inch, there would have been an improvement of only 1 db over the 3-db response achieved with 80 percent transfer at 400 cycles per inch.

In an effort to obtain high resolution, the original approach was to select an emulsion with very high resolving power and to use fiber optics to supply enough light from the CRT for exposure. The film selected was SO-243. However, light losses in the unfolding array were so great (80 percent) that it was necessary to use a faster film (Aerographic duplicating film) with a much lower resolving power in order to obtain sufficient exposure. In view of the unacceptably high losses encountered with the 8-inch-long unfolding array, study was initiated on the feasibility of using a 1/8-inch-thick fiber-optics faceplate as the screen of the CRT. The outer surface of this faceplate would then be in direct contact with the film to be exposed.

During the study on the faceplate approach, the optical department succeeded in obtaining spatial frequency modulation transfer response curves for both clad and unclad 6-micron fibers of 1/8-inch thickness. These curves are shown in Fig. 2-3. It can be seen that the limiting response is 1,450 cycles per inch, or approximately the same as that for the lens recorder, as shown in Fig. 2-2. Note also, the 50 percent response point for the fiber optics system is 320 cycles per inch as compared to 400 cycles for the lens system. The curve for the fibers is an average curve for unclad (low absorption) fibers. Fig. 2-4 shows the response for the best unclad

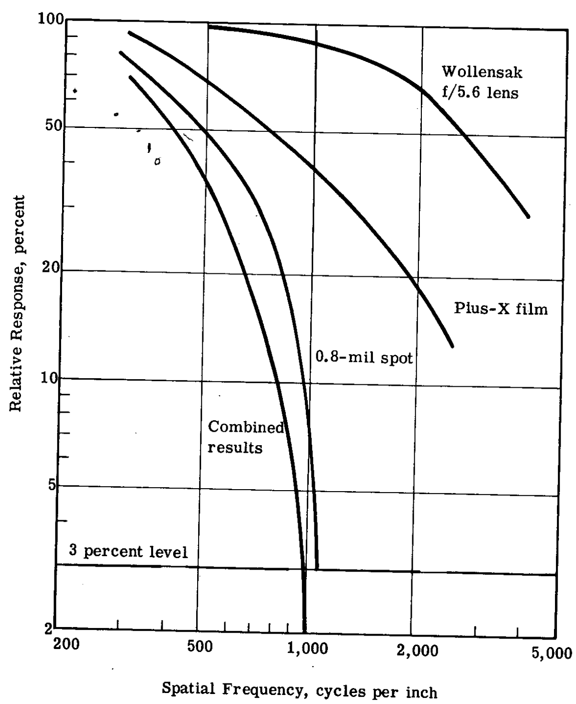

Fig. 2-1 — Individual and combined transfer functions for lens, film, and 0.8-mil spot

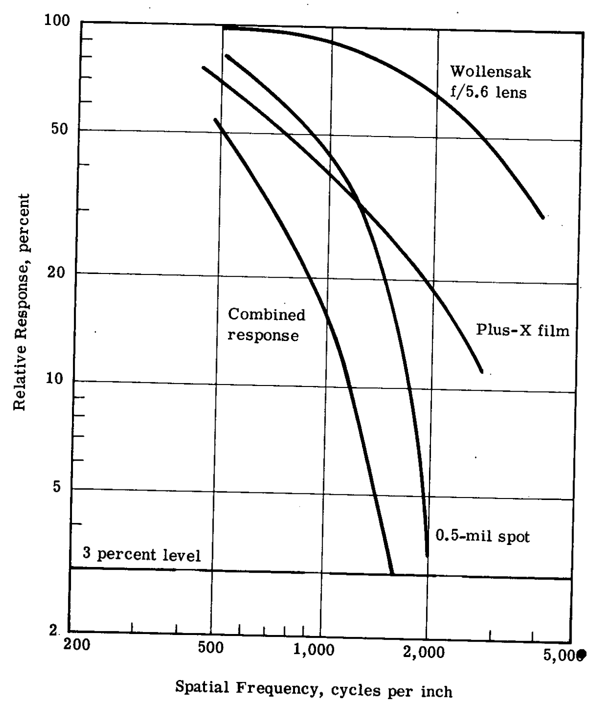

Fig. 2-2 — Individual and combined transfer functions for lens, film, and 0.5-mil spot

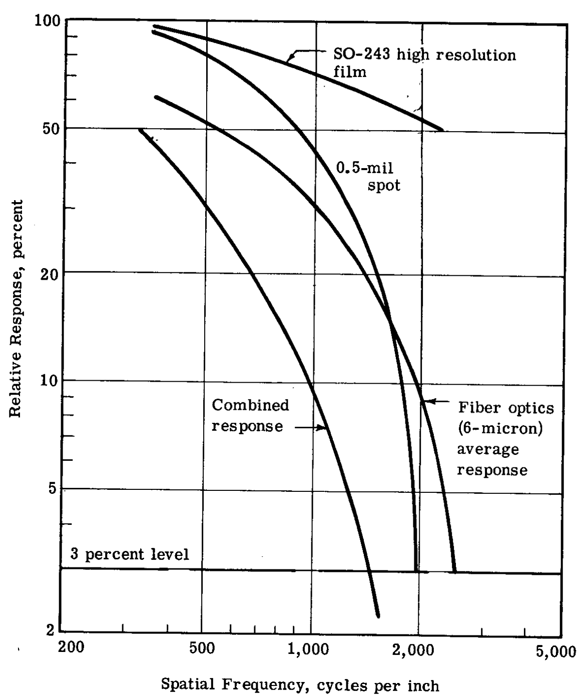

Fig. 2-3 — Individual and combined transfer functions for 1/8-inch-thick fiber optics bundle, 6-micron fibers, SO-243 film, and 0.5-mil spot

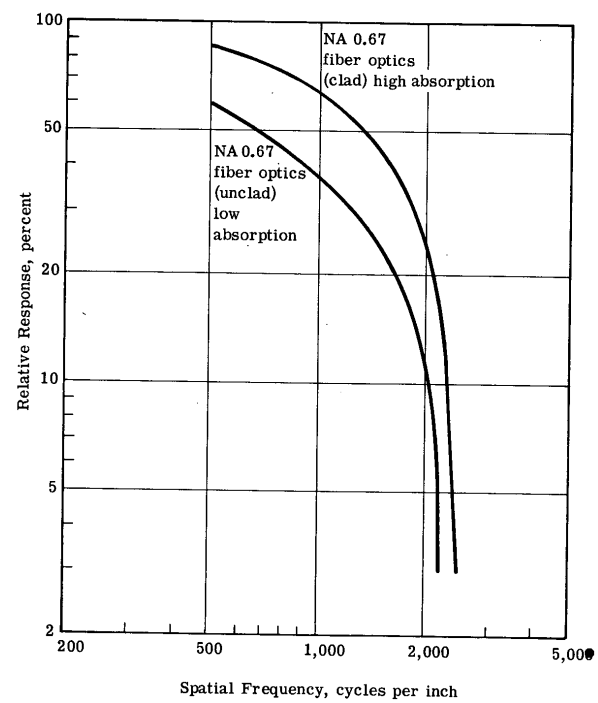

Fig. 2-4 — Transfer functions for clad and unclad fibers and clad fibers. The response depends on the orientation of the slit with respect to the fiber bundles. Considerable improvement over the lens recorder would have been obtained if we had been able to use the clad fibers; however, our experience indicates that clad fibers are too noisy, as shown by striations on the exposed film.

2.2 LINEARITY OF TRANSFER

Transfer function curves provide considerably more information than can be obtained from the limiting resolution number. The use of limiting resolution numbers arises largely from the need to express the resolving power characteristics of a system and the lack of instrumentation to produce meaningful numbers in any other form.

However, in the system under discussion, the limiting resolution does not directly indicate the performance capability of the system. It is more meaningful to describe the system performance in terms of the half power, or 3-db down point, on the response versus frequency curve.

Examination of Fig. 2-1 will show the 3-db down point for the 0.8-mil spot to be 500 cycles per inch. The recorder system response is 3 db at 400 cycles per inch. Therefore, if the film and lens response were increased to 100 percent at 500 cycles per inch, the best response the system could attain would be equivalent to the response of the CRT spot. This analysis demonstrates that little improvement (approximately 1 db) can be obtained by improving film and/or lens capabilities. A greater improvement could be realized by obtaining a CRT with smaller spot size.

One of the often cited advantages of a fiber optics system as compared to a lens system is the uniformity of resolution to the edges of the image plane. In the application under discussion, the improvement in edge resolution is highly desirable and was one of the main factors considered in making the original decision to use fiber optics.

Transfer modulation data for the Wollensak lens was made on axis and also 2 1/8 inches off axis. However, experienced optical engineers felt that the off-axis response was too optimistic and, therefore, this data has not been used in this report.

The rule of thumb generally applied for ascertaining edge resolution is that over a 15-degree field, the resolution will fall off by approximately 40 percent at the edges. This figure agrees with the results as measured by Wollensak, and is considerably greater than indicated by the transfer modulation measurement.

A decision was made to analyze this data and correlate it with other data obtained in more conventional tests. Fig. 2-5 shows the results. In performing this analysis, the response of the diffraction limited lens was computed for a wavelength of 455 millimicrons and an aperture of f/5.6 on axis. It is seen that the transfer modulation response as measured agrees quite well up to 2,000 cycles per inch, where the actual performance of the lens begins to fall off at a faster rate than the theoretical diffraction limited lens.

Table 2-1 indicates the Wollensak lens data as read from an exposure through a Wratten 47 filter onto Microfile film, with an aperture of f/5.6. The transfer modulation for Microfile film was plotted from Eastman Kodak data, and is shown. From these, an overall response for the Wollensak lens and film was computed. This response shows a limiting response of 3,000 cycles per inch (at the 3 percent cutoff point). The best limiting resolution read from the Microfile exposure was 2,000 cycles per inch.

There are several reasons for the frequent discrepancy between measured and computed response in the field of optics. First, the measured limiting resolution number is subjectively

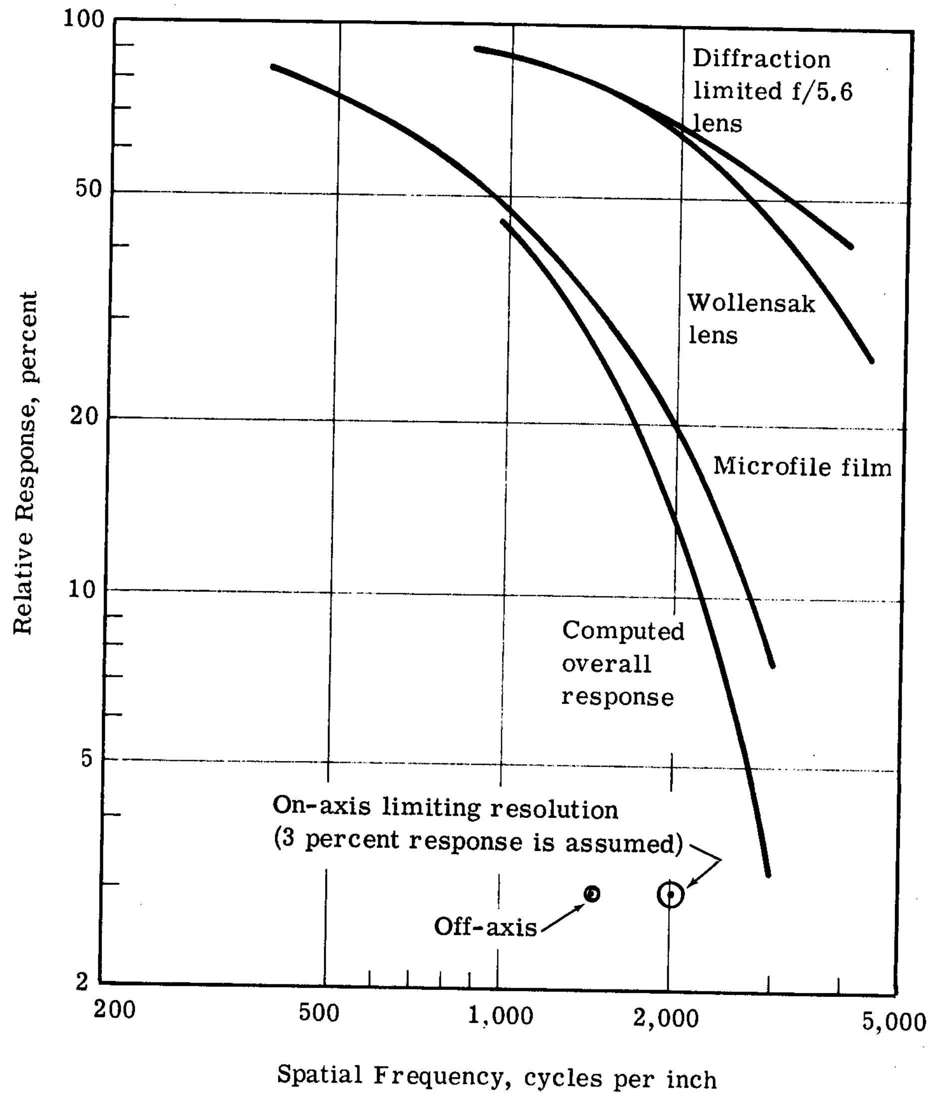

Fig. 2-5 — Individual transfer functions of Wollensak lens and Microfile film compared to limiting resolution points read from standard bar target exposed on Microfile film

Table 2-1 — Limiting Resolution of Wollensak Lens, L/MM

	Field Position				
Aperture	$-2\frac{1}{8}$ Inches Off Axis	−1 Inch Off Axis	On Axis	+1 Inch Off Axis	$+2\frac{1}{8}$ Inches Off Axis
f/2	57	72	81	72	57
f/2.8	57	72	81	72	57
f/4	57	72	81	72	57
f/5.6	57	72	81	72	57
f/8	57	64	64	64	57

arrived at, perhaps by only one observer. Second, control of the experiment to the required degree of precision is not always achieved. A third factor can occur in the development of the film. For example, Eastman Kodak computes the transfer modulation function in terms of the exposure required. However, this correction factor was not available for the limiting resolution measurements in Table 2-1. Further, in the case under consideration, the measured data was taken from one lens while the transfer modulation function was obtained by measuring another. The measured limiting resolution from a third lens was found to be on the order of 100 lines per millimeter on axis (2,500 cycles per inch).

The above discussions indicate that only the overall resolution characteristics of the system should be considered as indicative of the results to be expected, modified by the day-to-day changes in the operational characteristics of the system. The actual performance of the system depends on repeatability and stability of adjustments.

The lens recorder is capable of resolving 400 cycles per inch at the half-amplitude point for a linear system. Limiting resolution approaches 1,000 cycles per second. These numbers have been achieved in laboratory tests with a 0.8-mil-spot-size CRT. Unclad fiber optics, which produce minimum noise, did not match the lens capability on axis. Clad fibers surpassed the lens in resolution at all points in the image plane, but produced an intolerable amount of noise. The greatest opportunity for improvement of the system is in the improvement of the response of the CRT, since it is the weakest link in the CRT, optics, and film system.

2.3 STABILITY UNDER ENVIRONMENTAL CONDITIONS

Some of the effects of vibration in the recorder were examined on the optical bench. A swept frequency generator was used to produce a pattern of nominal focal length. At the same time that this signal was recorded, the trace was jittered by a second 50-cps signal applied to the centering coils. This has the effect of physically moving the CRT trace back and forth, simulating the effect that would be obtained if vibration were to move components of the optical path, such as mirrors.

A pattern (Fig. 2-6) with no jitter was focused using the bench optics and spatial filter into a single line (Fig. 2-7). This line had some side structure due to nonlinearities in the sweep circuit, but illustrates the effect. With the maximum amplitude square-wave jitter applied to the sweep (Fig. 2-8), the image was broken up into a number of lines (Fig. 2-9), all of which still appeared to be in focus. This also occurred, in varying amounts, at the other amplitudes of sinusoidal jitter. Thus, the introduction of periodic vibration frequencies can introduce ghosts of false spectrum lines in much the same fashion as a periodic error in the lead screw of a diffraction grating ruling machine. Since each grating (i.e., zone plate) is, in effect, generated slightly different each time, the ghosts will appear somewhat different each time.

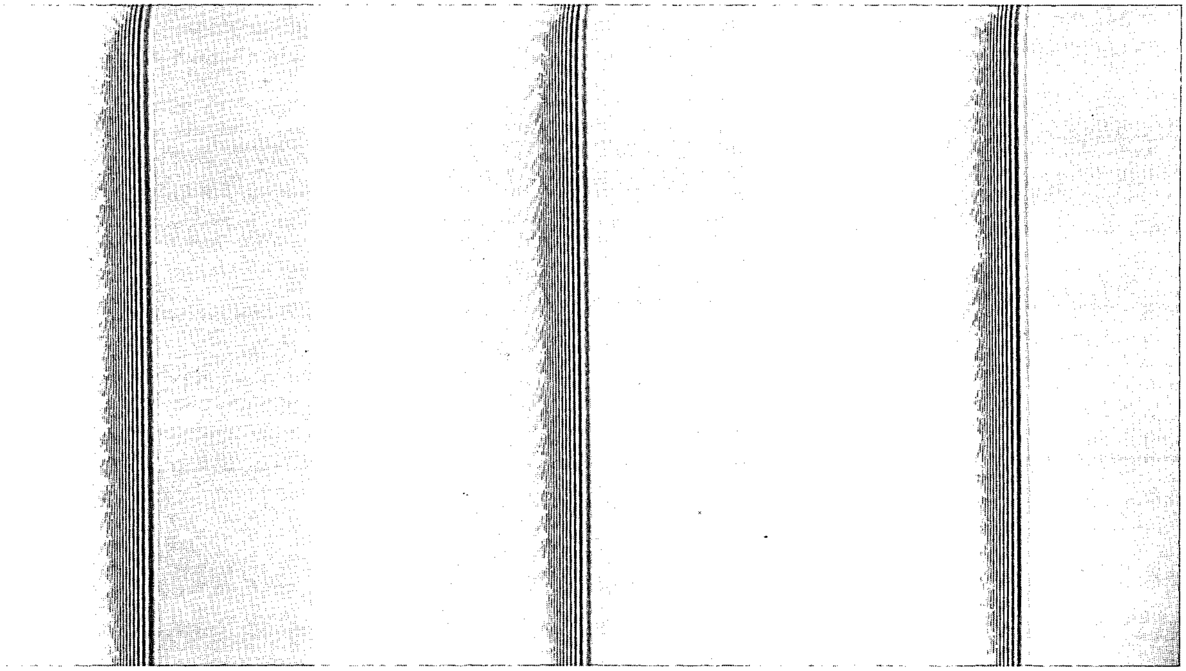

Fig. 2-6 — Normal swept frequency pattern

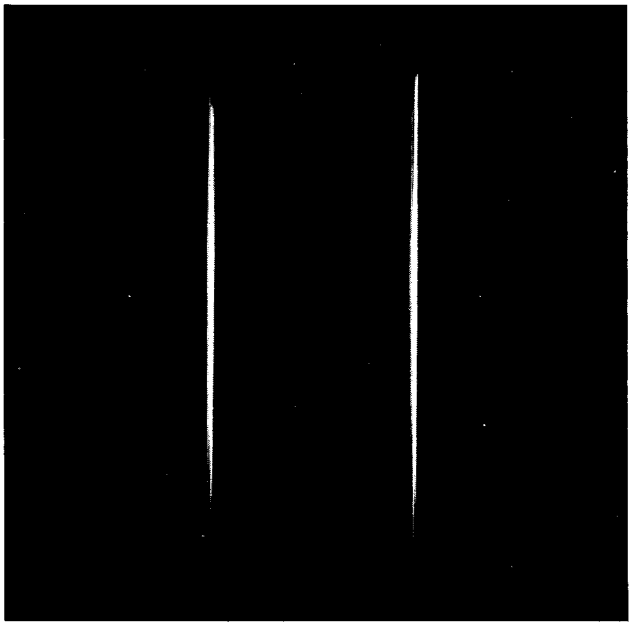

Fig. 2-7 — Spatial transform of normal swept frequency pattern, 0 order suppressed

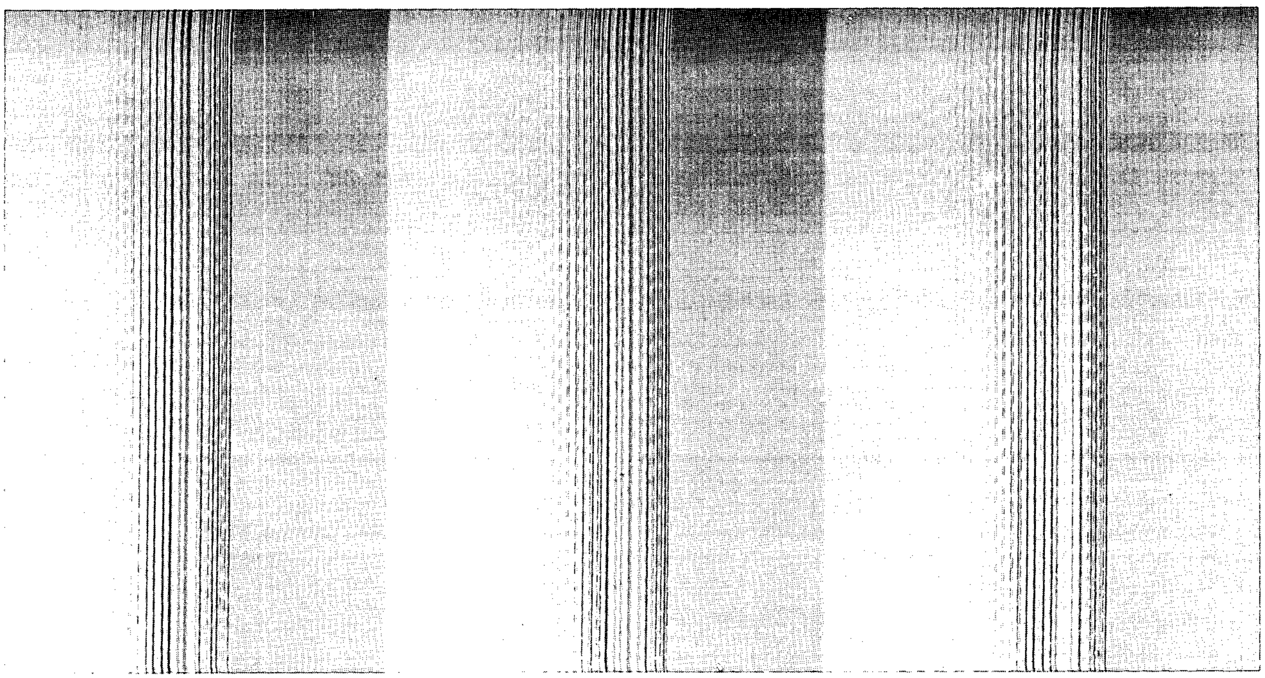

Fig. 2-8 — Swept frequency pattern in which jitter has been artificially introduced by applying a square-wave to electron beam centering coil

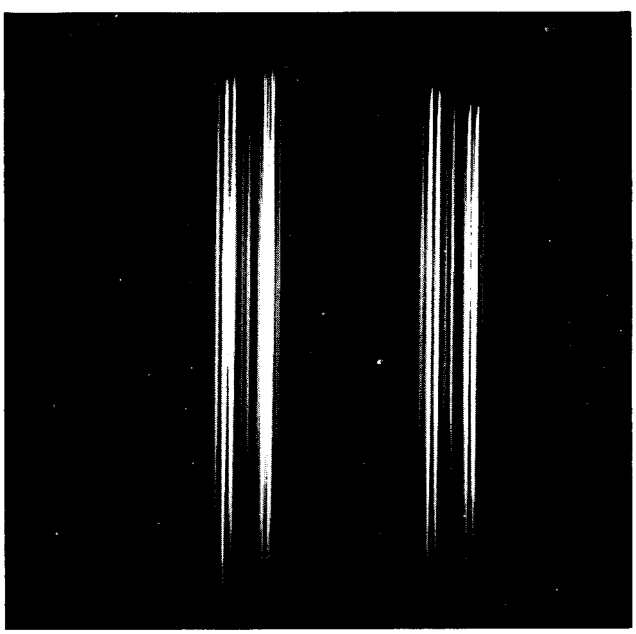

Fig. 2-9 — Spatial transform of jittered swept frequency pattern showing additional sidebands created by relative film-to-beam motion

3. EVALUATION OF GENERAL ELECTRIC CATHODE-RAY TUBE

Two GE Z4896 Microspot CRT's were delivered to Itek for operational evaluation in March 1962. The first tube had the serial no. 188-23, 62-17. The second tube had the serial no. 188-23, 2-13. The former tube will be designated as tube 1 and the latter as tube 2 throughout this report.

The operational feasibility tests on the GE Z4896 Microspot CRT's were not satisfactorily completed due to the malfunctions which occurred within both tubes. These malfunctions were determined to have been caused by breakdown due to ionization.

Tube 1 developed cracks and a puncture in the neck of the tube adjacent to the focus 2 lead-in wire and close to the filaments. The getters in this tube turned white, indicating that the vacuum no longer existed.

Tube 2 developed low cathode emission (cathode slump) and low light output after observed internal arcing and ion conduction within the tube.

While in operation, the line width of this tube was measured to be less than 0.001 inch at a low ultor current of 0.4 microampere. The astigmator control was varied for minimum line width and maximum ellipticity in the direction of travel. This resolution measurement appears to be compatible with that specified by GE when the results of each different measurement technique are normalized.

The limited operational experience indicated that the tube is extremely sensitive to voltage drift in the dc supplies which energize the alignment coil and the electrostatic focus controls. The alignment coil is also extremely sensitive to ac voltages which caused vertical trace jitter. The potentiometer controls to focus 1, focus 2, gate electrode, and the astigmator coil must be capable of good resolution to achieve the small spot size.

The Z4896 CRT development is an adaptation of the Z4862 tube design. The Z4862 is a developmental, ultrahigh resolution, 5-inch tube with a standard, flat glass faceplate. The light emitting material deposited on the faceplate is a short persistence PZB phosphor. The PZB phosphor is a vapor reacted screen commonly known as transparent phosphor.

The Z4896 tube has a fiber optics mosaic made by Mosaic Fabrications, Inc. This mosaic was fused to the faceplate of a 5-inch CRT blank by the Westinghouse Electronic Tube Corporation. The phosphor is a cataphoretic deposited P-11 type provided by Westinghouse. The remainder of the fabrication of the Z4896 CRT was done by GE using the techniques developed for the Z4862 tube.

These tubes were operated intermittently over a 5-month period. Prior to failure, tube 1 was operational for approximately 100 hours and tube 2 was operational for approximately 125 hours. The tubes were considered to be operating with only their filaments and low voltage electrodes energized.

Since the tube is not of a conventional design, a special power supply and an alignment control box had to be built. The alignment coil is provided by GE as a special accessory for the tube. This CRT requires eight different electrode voltages—exclusive of the deflection yoke—in order to produce a bright spot on the screen.

During preliminary tests, tube 1 displayed an interesting phenomenon. There were two bias voltages—-20 volts and + 1 volt—which could produce cutoff and near cutoff respectively (see Fig. 3-1). Two peaks of brightness could be obtained when going through this range of voltages. Tube 2 did not display this phenomenon.

With constant voltage settings on the electrodes, the brightness would fluctuate within intervals of a few minutes. Defocusing due to increasing the ultor current occurred as the bias voltage was decreased.

Discussions with a GE tube engineer revealed that the double inflections were caused by a minor 1/16-inch misalignment of the alignment coil assembly.

A coherent 10-megacycle-per-second sine-wave oscillator, gated by the line pulse (8 kilocycles), was used to modulate the intensity electrode. A resolvable dash pattern was observed on the face of the CRT at very low intensities. The bright dashes were separated from each other by a distance equal to their length. These bright dashes simulated an ellipse whose major axis was approximately 0.0032 inch and whose minor axis was less than 0.001 inch, since there was approximately a 3:1 correspondence between length and the height. The astigmator coil has a decided influence over the shape of the beam and can distort it in either direction.

3.1 THEORY OF OPERATION

The GE Z4896 tube is a new CRT design approach to achieve high resolution. This tube reportedly has the following significant advantages over other CRT's:

1. A spot size of 8 to 9 microns at a beam current of 1.5 microamperes
2. Low voltage drive required to modulate its intensity
3. Electrostatic spiral accelerator allowing dynamic focusing at low voltage and high writing rates

The tube has a radical gun structure which incorporates focus reflex modulation (FRM). A description of the construction and operation of the tube will be given for a better understanding of the technical discussion. The Z4896 is a 5-inch CRT with a 40-degree deflection angle. Fig. 3-2, is a simplified drawing of the microspot tube assembly.

The tube utilizes a cathode manufactured by Philips Metalonics Corporation. This cathode is very rugged and is capable of high emission density. An operational cathode current of 2 milliamperes is equivalent to an emission density of 3.94 amps per cm^2. The cathode was operated at an emission density of 11.82 amps per cm^2 for a short period.

The purpose of the collimator electrode is to deliver a parallel, unmodulated beam from the cathode to the modulator anode. A decelerating hyperbolic lens field is formed between the convex surface of the modulating anode and the gate electrode. With a low bias on the gate electrode, a virtual cathode is formed at the apex of the gate electrode. The electron optics achieves a 10:1 minification of the space charge at the emitting cathode to the virtual cathode at the entrance to the 0.0005-inch aperture. The emission density of the virtual cathode is approximately 39.4 amps per cm^2, if all the electrons emitted by the cathode arrive at the aperture and if the cathode current is 2 milliamperes.

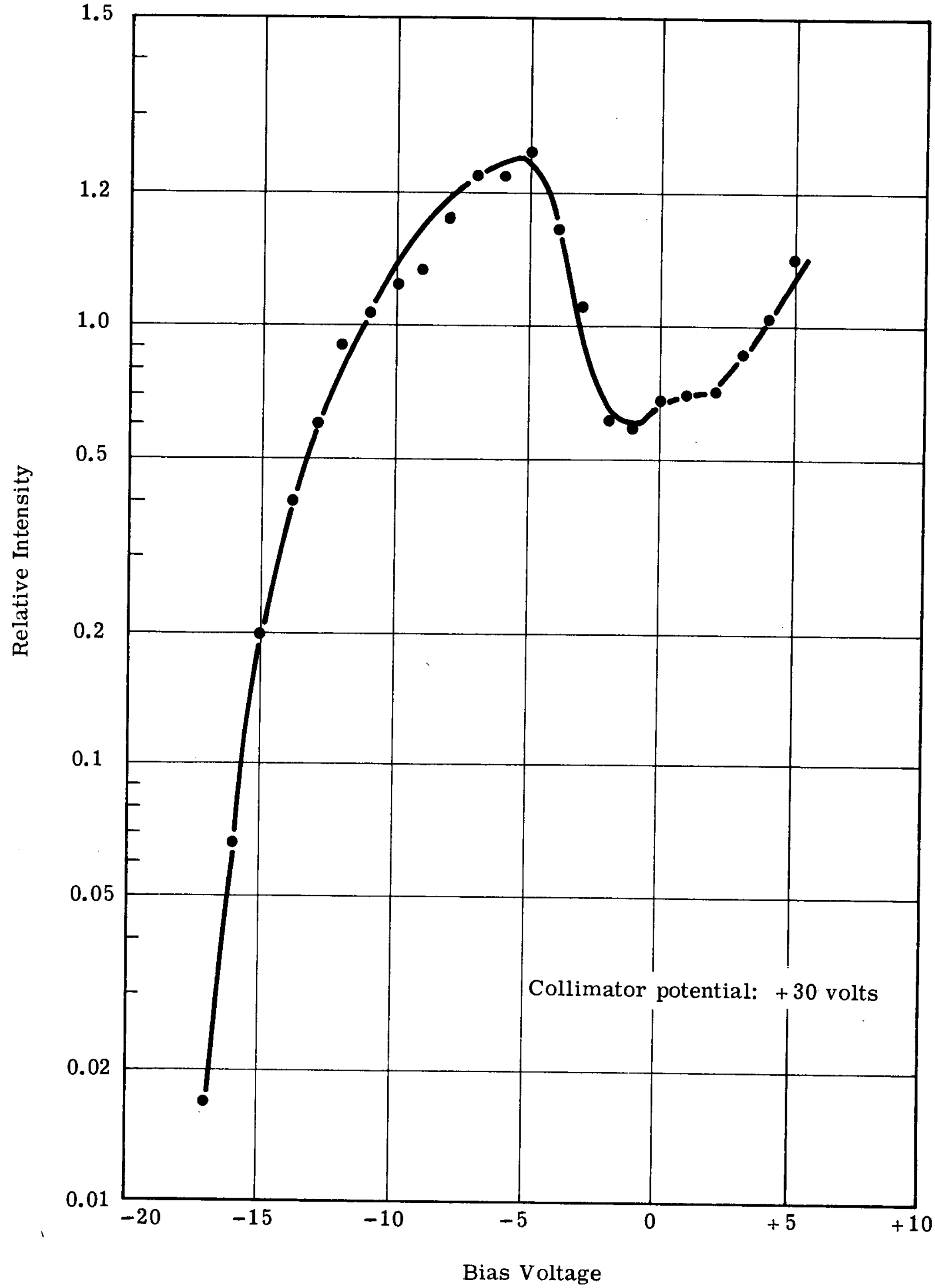

Fig. 3-1 — Relative intensity vs bias voltage

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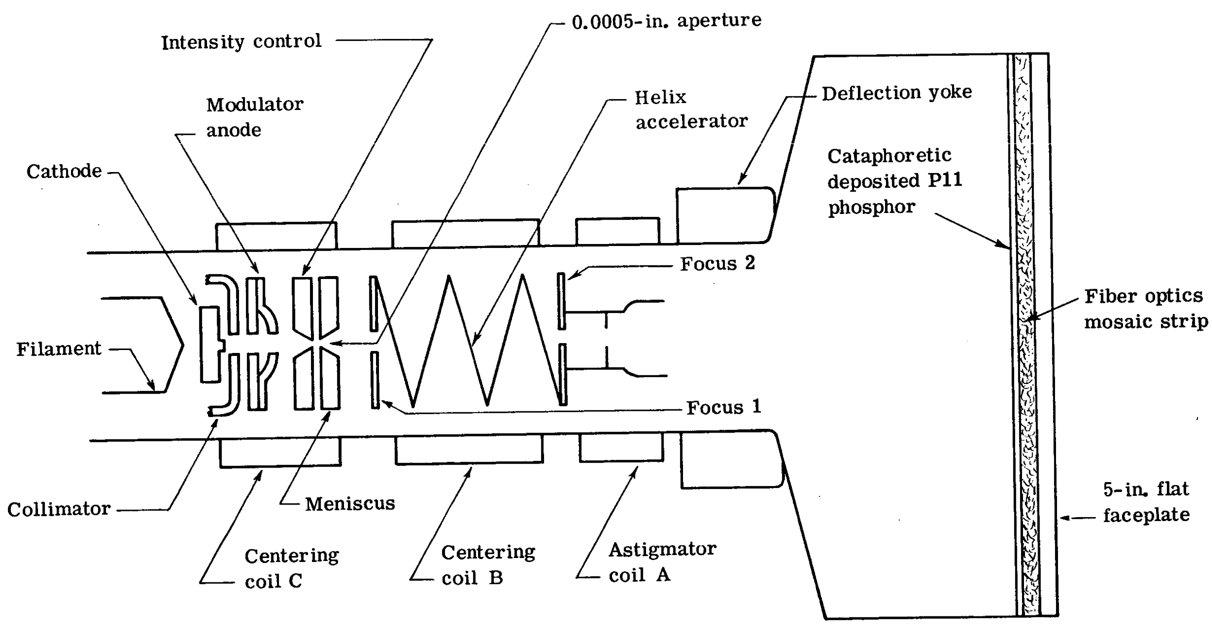

NOTE:
Coils A, B, and C are combined to form a single alignment coil (supplied by manufacturer)

Fig. 3-2 — Z4896 Microspot tube assembly

The meniscus electrode supports the spot defining, 0.0005-inch aperture and brings it very close to the virtual cathode region (less than 0.010 inch separation). The signal voltage at the gate determines the fraction of the current to go through the aperture; the remainder is reflected back to the modulator anode.

The forward current past the aperture diverges, but is reconverged by the short accelerating field which exists between the meniscus anode and the end plate of electrostatic focus 1 electrode. Electrostatic focusing is accomplished by the accelerating lens effect furnished by the helix accelerator. With focus 1 electrode at 300 volts, a beam size magnification of 0.6 is obtained. This voltage determines the object-to-screen minification.

The alignment coil performs two functions. Coils B and C are centering coils. Coil A is an 8-pole, fixed-position magnetic astigmator. To provide the proper field direction from this coil, two controls, driven by a common shaft, are connected to a dc source in such a manner that the sine-cosine relationship of the following equation is closely approximated

$$\Psi = \phi \cos 2\alpha + \phi_2 \sin 2\alpha$$

The C coil has considerable influence over the symmetry of the spot shape.

3.1.1 Tube 1 Operation and Testing

Tube 1 was set up and operating on 26 July 1962, with the special Walden power supply. A triangular current wave shape was applied to the Celco yoke to provide the horizontal trace. The tube was oriented so that the trace moved perpendicular to the fiber optics mosaic.

The full 12-volt regulated voltage was applied to the cold filaments since the Walden supply had no provision for controlling the initial current surge through the filaments. The cold resistance of the filaments was measured to be 1.5 ohms. Approximately 8 amperes of current surged through the filaments during the warmup period. Approximately 96 watts of power was dissipated by the filaments during the warmup interval. Normal operating values are 1 ampere filament current at 12 volts, or 12 watts of power.

After a short filament warmup period, the low voltages were applied to their respective electrodes. After turning on the low voltage supplies, the high voltages, focus 2 voltage, and the ultor voltage were applied. By adjusting the collimator and the gate controls, a broad band of light, approximately 1/2 inch high, was obtained over the full 4 inches of deflection.

By varying the various electrode parameters and the alignment coil controls, a bright line trace was obtained. An ultor current of approximately 1.5 microamperes was achieved during the short operating period of this tube. The trace was so bright it could be viewed in a well lighted room. The ultor current reading had two components, leakage current and beam current. The leakage current varied on the average from 0.4 to 0.6 micorampere. The ultor current reading quoted was the result of deducting the leakage current from the total current read on the microammeter. Subsequent investigations showed that the leakage current was a dark current generated by the CRT and not leakage from the meter and its associated leads.

Since there was no vertical component applied to the horizontal trace, no attempt was made to measure the line width accurately during this phase. (If there were any hysteresis in the yoke, the return trace would be shifted in the vertical from the forward trace, providing an erroneous line width.) A preliminary check indicated that the line width was less than 0.002 inch at this time.

Best focus was obtained with focus 2 electrode operating at positive 210 volts, which is a low value. According to the performance characteristics published by Dr. K. Schlesinger, beam or ultor current would increase with low focus 2 voltage, but object-to-screen minification or resolution would decrease.

Vertical jitter in the horizontal trace was being generated by spurious modulations in the Walden filament supply. This voltage was also applied to the alignment coil. Shifting to two independent supplies, one for the filament and the other for the alignment coil, eliminated this jitter. In addition, this modification allowed us to warm up the filaments slowly without introducing the large surge of current.

Failure of the power supply and other troubleshooting problems permitted only 8 hours of operation of the tube during that week. Tube 1 was put into operation again 5 days later, after considerable modification to the setup. The sweep was much wider on the face of the tube for the same drive current which had been applied to the yoke on the previous week. The trace appeared defocused and also was extended in the vertical direction. The brightness was intermittent with constant gate voltage.

Within 2 hours of operation, the trace disappeared with all the requisite voltages applied to the various electrodes. Visual inspection indicated that the filaments had gone dark. Measurements indicated that the resistance of the filament was 10,000 ohms. There was high resistance from the filament to the cathode and the collimator (270 kilohms). The resistance of the cathode to the collimator measured 8.5 kilohms.

When the tube was taken from its mount, a visual inspection under magnification showed a depression and a puncture in the neck of the tube near the focus 2 (5 kilovolts) lead-in wire. This rupture on the neck was very close to the filament and the tube base. The area around the puncture had a crack. The glass appeared burnt, as though arcing had occurred. No arcing sounds were heard when the tube failed. Close examination of the getters, which appeared white and transparent, was sufficient evidence that the tube had "gone to air."

There are valid suspicions that the tube ionized prior to failure. The total operating time for this tube was approximately 100 hours, 10 hours of which were under our control. However, the tube had been undergoing intermittent operation over a period of 5 months.

3.1.2 Operation and Testing of Tube 2

With the failure of tube 1, tube 2 was checked carefully for any visual imperfections before "firing it up." Except for scratches on the neck, close to the lead-in wires to the focus 1 and focus 2 electrodes, and also except for the flaking of a portion of the dag coating, the tube appeared to be well constructed. The cold resistance of the filaments, using a VTVM, was measured to be 1.5 ohms. The resistance between the filaments to other electrodes was very high. The resistance of the spiral accelerator (focus 1 to focus 2) was 21 megohms.

This tube was placed into a similar setup as was used to test tube 1. The filament voltage was increased slowly until the rated current of 1 ampere was reached. A Simpson Therm-O-Meter, with a thermocouple for the sensing element, was taped to the neck of the tube to monitor the temperature of the glass near the filament. This temperature at times rose to 215 °F when 12 watts were dissipated by the filament.

The cathode was connected directly to ground through a milliammeter in order to monitor the cathode current. With the filament and the low voltage electrodes energized, 6 milliamperes of cathode current were allowed to flow for a short period of time. Best readings (maximum ultor current) were obtained with 0.1 to 0.4 milliampere of cathode current.

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The Walden supply failed completely for the second time and was removed from the test setup. Separate, well regulated supplies were used to furnish the various voltages. An 0- to 10-kilovolt Fluke supply, variable in 1-volt increments, was used to energize the focus 2 electrode. The ultor voltage was supplied by a well regulated and filtered high voltage supply.

A maximum ultor current of 0.4 microampere was obtained from this tube. The ultor voltage was 15 kilovolts. Focus 2 was at 4,436 volts. Focus 1 was at 215 volts. Cathode current was measured to be 0.4 milliampere. The total current to the alignment coil was 74 milliamperes.

A step of current was applied to the vertical winding of the deflection coil to separate the forward and return trace. The line width was measured to be approximately 0.0008 inch. The technique employed was as follows:

A single trace was observed at a magnification of 60× with a Bausch and Lomb Bi-ocular microscope. One eyepiece had a scale whose smallest unit was 0.0005 inch. By fitting the trace within less than two of these divisions, the above line width was obtained. The error in measurement was caused by determining the exact edges of the trace.

GE ultilizes the shrunken test pattern technique for measuring line width. Using the shrunken raster technique, the line width A, specified by GE, is 0.0005 inch, at an ultor current of 1.5 microamperes.

After obtaining these resolution results, the tube was allowed to operate without changing any parameters. After an hour of operation, the ultor current had dropped to 0.1 microampere. Changing the various controls would not increase the ultor current back to its original value. The trace across the fibers under 60× magnification appeared discontinuous at the interface between two fiber bundles. In addition, "strands" of light appeared to shoot off for some distance in this area.

The next time the tube was put in use it was allowed to warm up for a longer period than usual and the low voltages were applied. When the focus 2 voltage was applied in 1-kilovolt increments up to 3 kilovolts, arcing was heard within the tube. With the ultor voltage off, a wide trace, 1/2 inch vertical, 4 inches horizontal, appeared on the face of the tube. This large trace was presumed to be spurious radiation. When the arcing stopped, the ultor voltage was turned on and two fine bright lines were observed within the large spurious radiation trace.

The supplies to the tube were turned off and the alignment coil was removed from the neck to permit observing the gun as each voltage was applied to the requisite electrode. The room was darkened and the low voltage electrodes were energized while keeping the gun section of the tube under close observation. No visible or audible effects were noted during this phase of the turn-on period. The focus 2 voltage was raised very slowly. At 3.9 kilovolts, an ion conduction trail was noted from the focus 2 lead-in wire to the gun section. This event occurred two times. The conduction trail extinguished and would not repeat. The focus 2 voltage was raised slowly to 4.9 kilovolts (operating voltage). Arcing was visible and audible from the focus 2 lead-in to the gun section. The arcing disappeared within a short time. The alignment coil was placed on the neck of the tube and the tube operated at lower brightness for 2 hours. The ultor current remained low, less than 0.1 microampere.

The tube was allowed to warmup for over an hour the following morning with filaments and low voltage electrodes energized. This was done in an attempt to allow the getters to absorb some of the ions. When focus 2 voltage was turned on slowly, spurious radiation was seen on the face of the tube at about 3 kilovolts. This radiation disappeared within a short period. The tube presented a narrow trace when the ultor voltage was applied. Ultor current became difficult to measure because it was such a small portion of the leakage current. Brightness became lower and lower with elapsed time.

The cathode current could be adjusted to a maximum of 2 milliamperes by varying the collimator voltage. However, this current would decrease to 0.1 milliampere and less within a short period without changing any of the controls. This phenomenon is known as "cathode slump." Varying the collimator voltage in the region of −60 volts caused the cathode current to change its direction of flow.

The low cathode emission can be caused by cathode poisoning. The Philips cathode contains barium. Barium in the cathode surface can act as a getter of the ions in the tube. Ultimately, the cathode area is reduced and its emission lowered.

Low cathode emission and corresponding low brightness made the tube inoperative for test purposes. A representative of GE saw tube 2 operate and took both tubes back to Syracuse on 17 August 1962, for checking and possible repair.

A total of 125 operational hours was put on this tube.

3.2 POWER SUPPLY PROBLEMS

Some of the difficulties encountered during the operation of the tubes were caused by the special power supply. This unit had been designed to provide the seven different voltages required by the various electrodes. The specifications for this power supply reflected the opinion of GE tube engineers that these voltage ratings were not critical. However, size and weight would be critical for the Project 9134 application. The power supply did not operate reliably nor did it meet specifications.

The Walden power supply was checked out by the Itek Instrument Department on 27 July 1962, prior to connecting it to the GE Z4896. Only the low voltage supplies were tested, because this department does not have the equipment to measure the high voltage supplies accurately. Table 3-1 is a comparison of the quoted specifications and the measured values.

This table clearly indicates that the Walden power supply did not meet its published specifications. In addition, the ripple specifications were obtained from rms voltmeter measurements which had a relatively low bandwidth. Peak-to-peak values under actual operational tests were more significant to some of the trace jitter problems encountered. While tests on the CRT and power supply were not completed, sufficient data was accumulated to indicate that the power supply requires modifications in order to provide the requisite regulation and ripple, as well as proper operational reliability.

Output 1 (filament and alignment coil supply) presented the following problems in addition to not meeting the quoted specification of 0.1 percent for line and load regulation. The filament voltage supply could be varied from 10.8 volts to 13.2 volts only with the appropriate control. The cold resistance of the filaments of the Z4896 was measured to be 1.5 ohms. With the filament voltage set to approximately 12 volts, the initial current surge could be as high as 8 amperes. Approximately 96 watts of power would have to be dissipated at the tube filament electrodes. Using the laboratory power supply, the filament voltage was increased to the rated value gradually, so that the filament current did not exceed 1 ampere.

In Table 3-1, it appears as though output 1 satisfied its ripple specifications. However, the measuring instrument could not follow the high frequency pulses which were modulating the dc voltage. These pulses measured 0.3 to 0.5 volts peak to peak on a Tektronix scope. These pulses

Table 3-1 — Quoted and Measured Specifications of Walden Power Supply

		Quoted Specifications				Measured Specifications		
Description	Voltage	Current	Line Regulation, percent	Load Regulation, percent	Ripple, percent	Line Regulation, percent	Load Regulation, percent	Ripple,* percent
Output 1, filament and alignment coil supply	12 ±5% (10.8 to 13.2)	3 amps	0.1	0.1	0.1	0.31	0.96	0.018
Output 2, modulator anode and meniscus supply	550 ±5%	2 milliamps	unreg	unreg	unreg	7.94	6.27	1.17
Output 3, focus 1 supply	200 to 400	1 milliamp	0.1	0.1	0.1	0.31	9.4	0.037
Output 4, collimator supply	−20 to +50	10 milliamps	1.0	1.0	1.0	0.54	32.9	0.022
Output 5, intensity supply	−80 to +50	1 milliamp	1.0	1.0	1.0	0.67	41.5	0.01

* Ripple measured as rms value.

had sufficient amplitude to cause vertical jitter to the horizontal trace. (Output 1 was also used for the alignment coil.) A separate power supply reduced this jitter on the trace so that it was not visible with a microscope.

The specifications published by GE for the Z4896, serial no. 188-23, 62-17 indicated that the modulator and the meniscus anode (A_1 and A_2, respectively) should be at the same potential of 550 volts. However, preliminary tests indicated that with A_1 at 550 volts and A_2 at 300 volts, best results were obtained. These voltage settings are more in agreement with those recommended by Dr. K. Schlesinger.* Under operating conditions, output 2 was approximately 600 volts at the minimum setting of its control and could not be reduced to 550 volts.

Output 3 had a 0.3-volt, peak-to-peak, 120-cycle ripple riding on its dc voltage. A decoupling capacitor reduced this to a negligible amount.

Varying output 4 could produce more than 6 milliamperes of cathode current. This current would permit excessive cathode loading. It was necessary to monitor the cathode current in order to keep it under 3 milliamperes.

Because it was thought at the time that the GE tubes might still be utilized, a new, more conservative set of power supply specifications was drawn up. While it is possible that size and weight limitations might pose problems in the construction of these power supplies, it was thought that more experience with the Z4896 CRT might reveal areas where compromises with specifications might be acceptable.

The new specifications are as follows:

1. Output 1 — Filament Supply
   0-15 dc at 3 amps, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour
   Voltage balanced to ground
2. Output 2 — Modulator Anode and Meniscus Supply
   550 dc ±5 percent at 20 ma
   Total regulation (line and load) and ripple, 1 percent
3. Output 3 — Focus 1 Supply
   200 to 400 dc at 1 ma, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour
4. Output 4 — Collimator Supply
   −20 to +60 dc at 10 ma, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour
5. Output 5 — Gate Supply
   −80 to +50 dc at 1 ma, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour
6. Output 6 — Focus 2 Supply
   5 ±1 kv dc at 1 ma, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour

*K. Schlesinger, Focus Reflex Modulation of Electron Guns, IRE Transactions on Electron Devices, ED-8(3):227 (May 1961).

7. Output 7 — Ultor Supply
   17 ±3 kv dc at 50 microamperes, adjustable
   Total regulation (line and load), ripple and stability of 0.1 percent in 1/2 hour

8. Output 8 — Alignment Coil
   0 to 10 dc at 300 ma, adjustable
   Total regulation (line and load), ripple* and stability of 0.1 percent in 1/2 hour

3.3 CONCLUSIONS

1. The basic cause for both tube failures appears to be excessive internal ionization.

2. The ionization accumulation is a function of time.

3. The tubes have an excessive dark current.

4. Below the rated ultor current, the tube approaches the specified line width.

5. The double inflection as a function of grid drive may be caused by the misalignment of the alignment coil and should be investigated further.

6. The deflection yoke and the alignment coil should be positioned and held accurately on the neck of the tube.

7. Voltage drift of the supplies, which energizes the alignment coil, focus 1, focus 2, and the gate electrode must be kept to a minimum.

8. The filament current should be held to 1 ampere during the warmup period until sufficient test data (cycling of the filament voltage) indicate the tube and the filaments can withstand the initial surge of power.

9. High resolution potentiometers are required to control precisely the voltages to the following electrodes: focus 1, focus 2, and gate, as well as the astigmator field amplitude control.

10. Most of the voltages applied to the various electrodes must be well regulated and filtered, contrary to the opinion of the GE tube engineer, until sufficient operational data prove otherwise.

* Tube is sensitive to high frequency ripple in the alignment coil. This test should be made with an oscilloscope or wide bandwidth rms meter.

4. FIBER OPTICS TRANSMISSION CHARACTERISTICS

Two fiber bundles were evaluated, both as to their light transmission characteristics and their individual resolution capabilities. One of these bundles was made up of 5-micron unclad fibers, the other of 7-micron jacketed fibers. Both were similar in external configuration, roughly 1/2 by 2 inches, and positive planoconvex cylindrical in shape. Also supplied were (1) a motor driven mockup, (2) two slits on film of 14.5- and 25-micron widths, and (3) a quantity of Dow optical coupler no. XL-2-0057.

The evaluation consisted chiefly of two parts: (1) tests were made in which the film was exposed while it was moving across the slit/fiber plane, in an effort to determine the geometry or stria effects on film, and (2) static resolution tests were made in order to determine by means of contact printing techniques the actual resolving capability of the individual bundles.

4.1 PROCEDURES

Prior to any dynamic testing, the film slits were examined through a microscope and appeared to be quite uniform throughout their central area. However, numerous pinholes were discovered; these were opaqued, with the area adjacent to the slit ultimately being backed with an opaque paper.

In adhering the film slit to the fiber bundles with the Dow coupler, it was discovered that care must be given to ensure that all air was removed from the space between the two, or the resulting air belt would cause definite changes in density on the film. These changes vary with pressure. Final tests were made without the use of the coupling compound, since early testing showed little difference from the final results and since the coupler is difficult to remove. All tests listed were made with the 25-micron (0.001-inch) slit.

By means of the Welch Densichron densitometer, the following transmission values were established for each of the fiber bundles.

	Percent Transmission
7-micron clad fibers	75.8
5-micron unclad fibers	91+

These values were read with the 2150B probe, in which the spectral response is from 4,000 to 6,000 Å.

The following three systems were used in the dynamic tests.

1. The motor driven mockup, as supplied. Trial and error determined that a 60-watt lamp, at 120 volts, fully shielded and baffled, plus a sheet of flashed opal glass, with a sheet of diffuse acetate just beneath the printing platen, would provide adequate, even, and diffuse illumination.

The Spectra meter showed this plane to have a surface brightness of 210 foot-lamberts, and this combination was used in all tests involving the mockup. Lateral banding, caused by erratic drive, was subdued somewhat by finally using a rubber drive roller as the takeup spindle. A simple jig was devised to maintain fiber position as the film was transported. The film slit was taped to the printing aperture, and could not move. Table 4-1 shows actual drive speeds based on the 1½-inch diameter of this rubber spool. The optimum dial setting was found to be 90, on the Hi range, quite close to the desired 2.5 inches per second drive rate.

Table 4-1 — Drive Speeds in Inches per Minute

Dial Setting	Range Hi	Range Lo
30	47.1	28.8
40	53.4	44.0
50	73.1	56.6
60	94.6	85.1
70	116.6	85.2
80	138.2	102.9
90	150.8	110.5

2. A Gaertner slit was obtained, adjusted to a width of 0.001 inch, and attached to one end of a 3-inch-diameter mailing tube. At the other end, approximately 6 feet away, a 16-volt point source lamp was attached. Exposures were made by pulling the film across the slit by hand. This method of transport did not prove satisfactory, and resulted in lateral banding, in addition to an erratic direction of travel. However, the differences between films exposed with and without the fibers was apparent. Strips exposed through the fibers showed longitudinal variations in density that were not in evidence on film exposed to the slit alone.

3. To minimize the effects of erratic drive, a method was devised in which gravity was utilized as a drive (Fig. 4-1). Basically, it involved a clip release at the top of the test strip, with a weight at the bottom, plus a means of guiding the film past the slit/fiber exposure area and into an air chamber. Added to this were such refinements as a velvet dust trap/brake, with a tube beneath the weight to control the rate of fall. The light source was a 1493, 7½-volt lamp, powered by a 6-volt battery, and diffusion sheets were added to the lamp as required. This free-fall system proved to be quite satisfactory and films made with this method showed no adverse effects traceable to drive mechanisms. Again, however, a difference existed between films exposed through the fibers and those exposed to the slit alone. Shims were added to provide equal pressure in each case. The stria on the films exposed through the fibers is evident, and can be seen in Figs. 4-2 and 4-3. In these figures, the top strip was exposed to the 0.001-inch slit with no fibers, while the middle strip was exposed to the slit and the 5-micron bundle, and the bottom strip was exposed to the slit and the 7-micron bundle.

In all of the above tests, Linagraph Pan was the film used. However, Tri-X, Pan-X, high contrast copy and Royal-X-Pan were tried also, but greater control plus availability, gave the Linagraph a slight advantage. Developer in all cases was D-19 in a Nikor tank with processing times of 3 to 4 minutes.

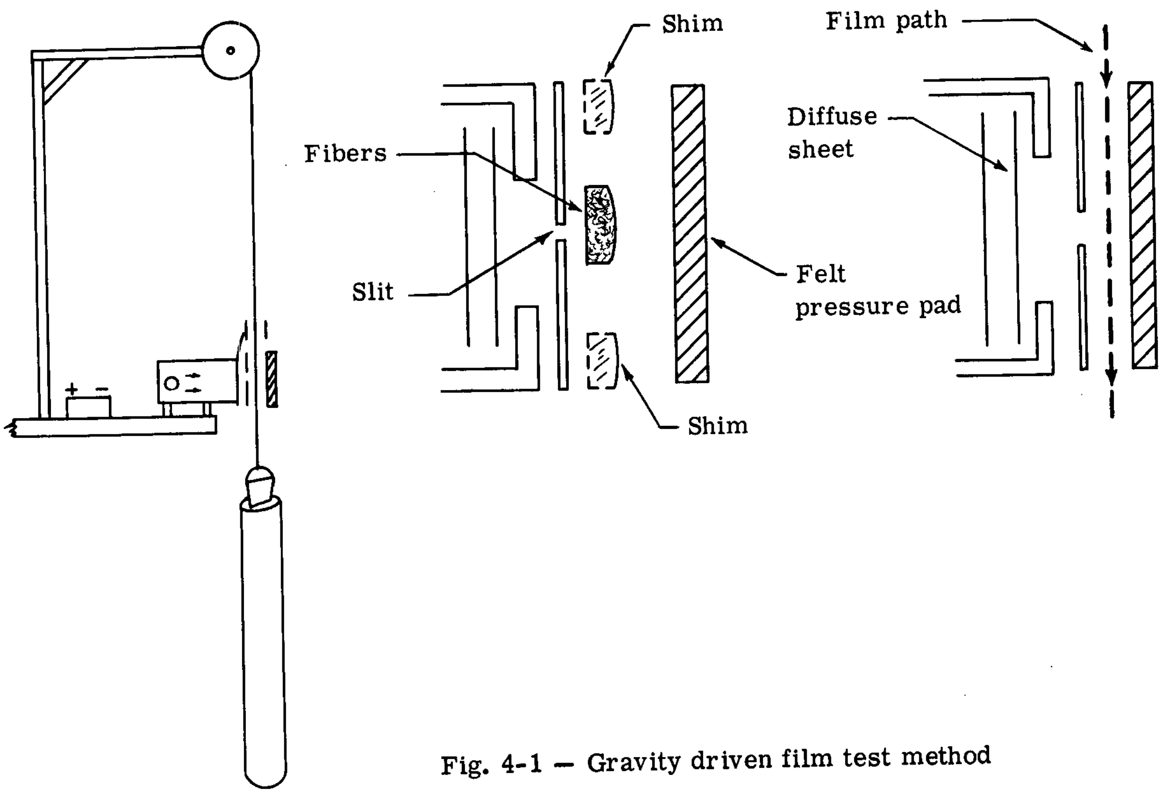


Fig. 4-1 — Gravity driven film test method

4.2 STATIC RESOLUTION TESTS

Examination of the two fibers under magnification showed that in the 5-micron bundle, a variance in diameter of the individual fibers was apparent. Figs. 4-4 and 4-5 illustrate this condition. To provide static resolution data, a small printer was devised which incorporated both a point and a diffuse source, adequate rubber padding and a solid base (Fig. 4-6). Due to the convex surface of the fibers, the test targets were kept in close contact by means of an elastic tension system, which proved to be quite dependable. The master targets used for these tests were of high quality, in both high and low contrast, with each capable of 228 lines per millimeter. Film used for these static resolution tests was high contrast copy, developed in D-19. Results were repeatable, and the values listed in Table 4-2 are optimum. Figs. 4-7 to 4-10 illustrate each condition.

Table 4-2 — Resolution, Lines per Millimeter

	High Contrast		Low Contrast	
Fiber Type	Diffuse	Point	Diffuse	Point
7 micron, clad	80.7	102	71.9	64
5 micron, unclad	128	102	80.7	71.9

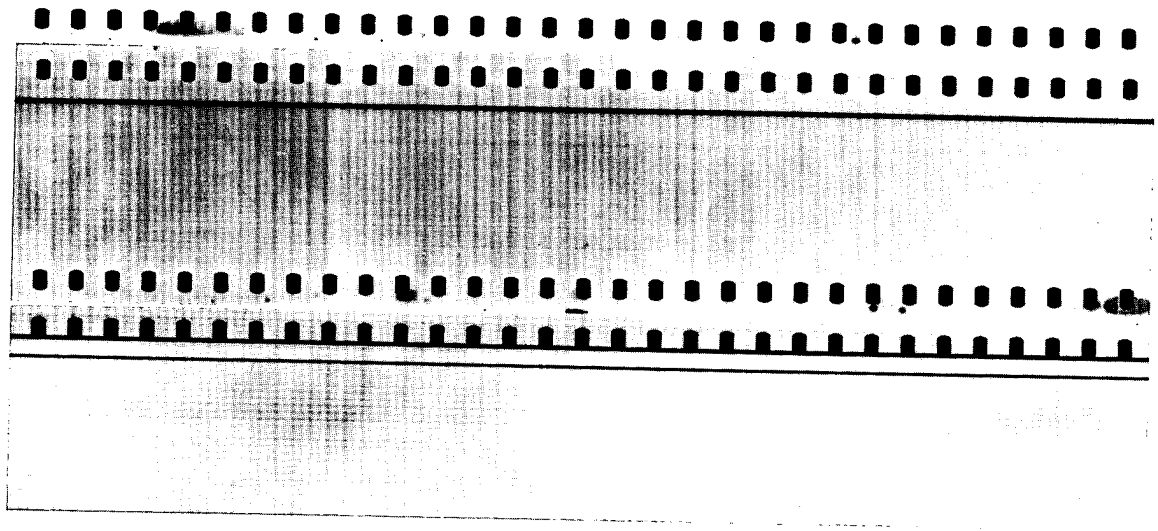


Fig. 4-2 — Film strips exposed using the motor driven mechanism

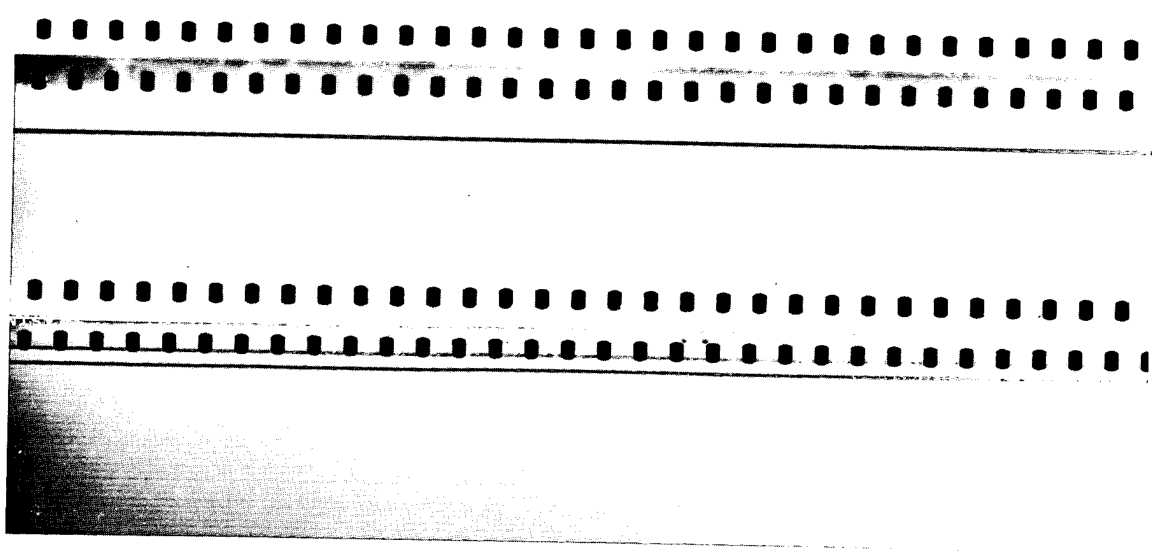


Fig. 4-3 — Film strips exposed using the free-fall mechanism

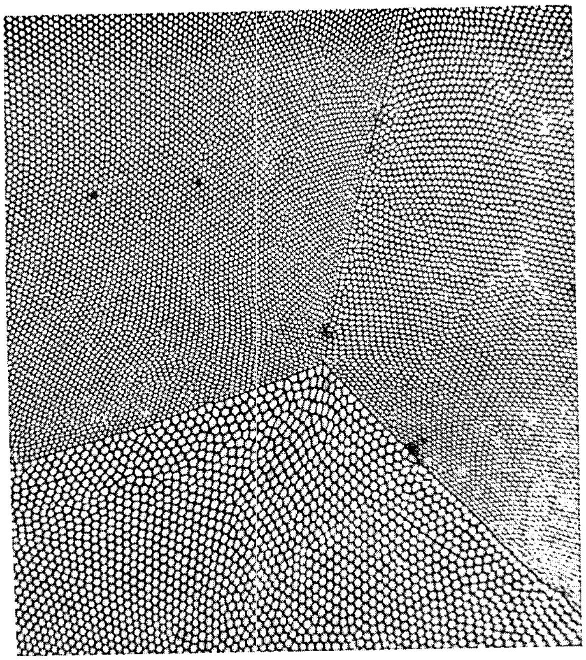


Fig. 4-4 — Variance in diameter of 5-micron unclad fibers at 160×

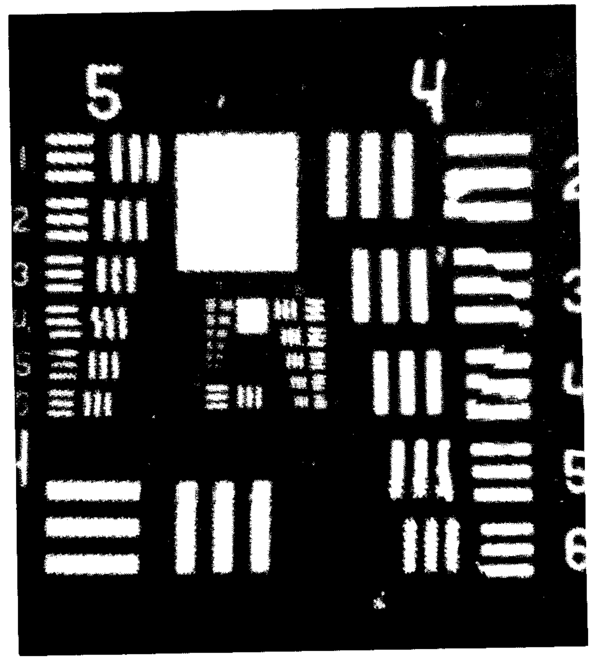


Fig. 4-5 — High contrast target showing variance of diameter of 5-micron unclad fibers at 80.64× (no optical coupler was used)

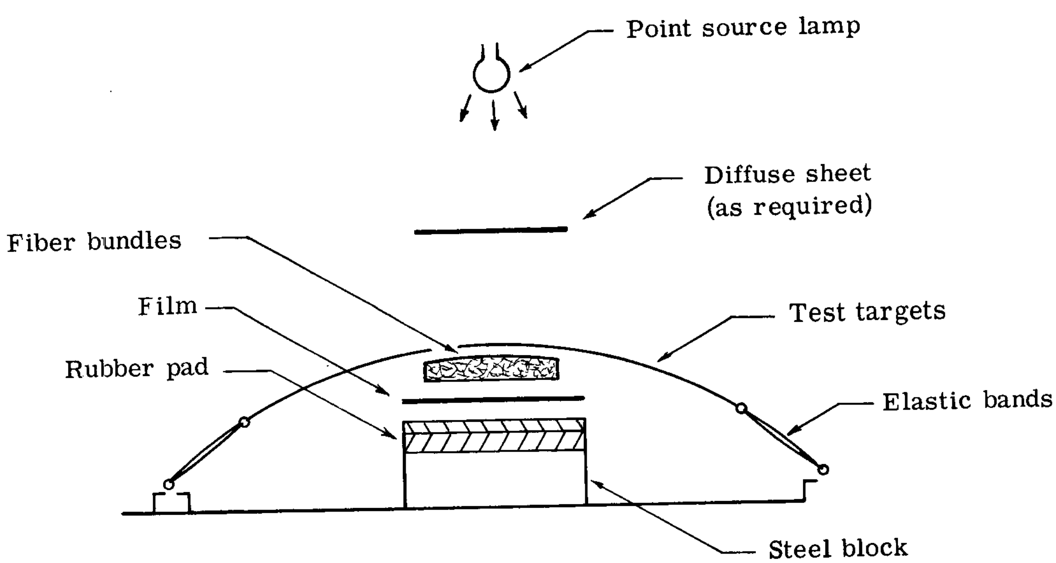
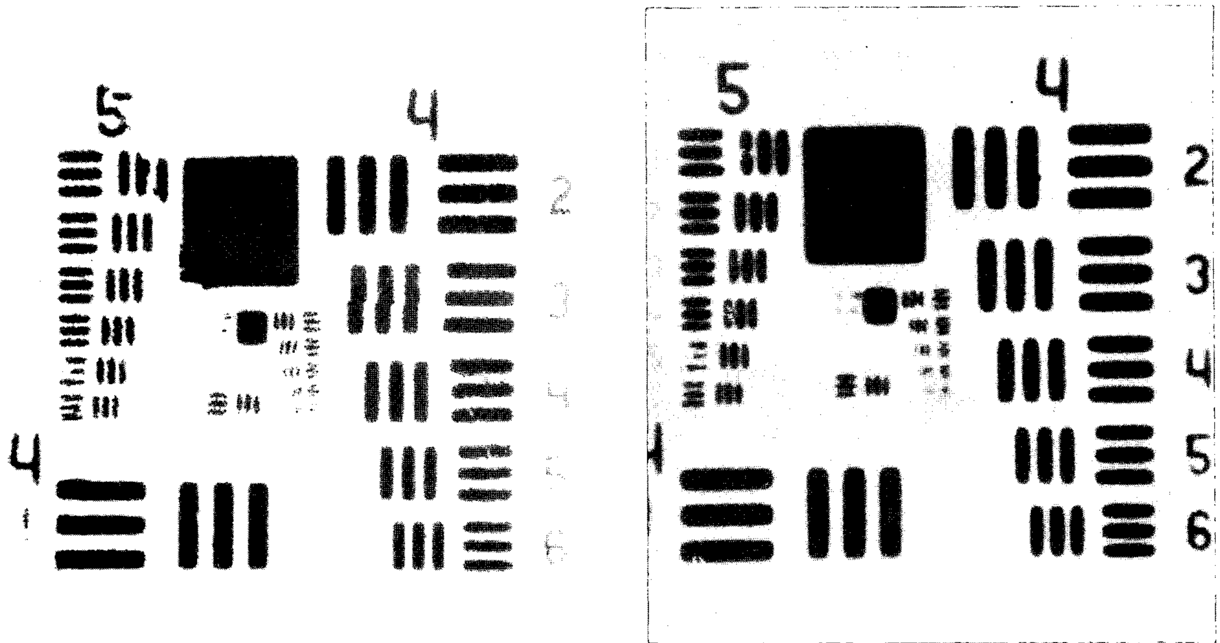
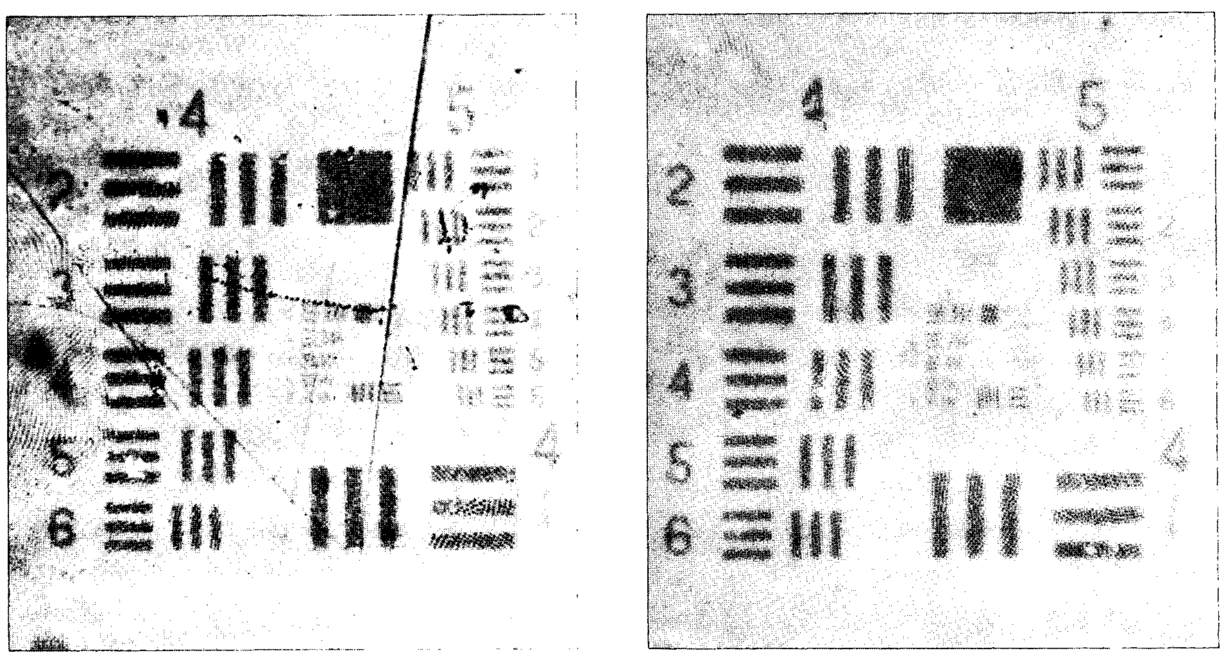


Fig. 4-6 — Printer used for static resolution tests



(a) Diffuse source illumination, 102 L/mm, (80.64×) (b) Point source illumination, 102 L/mm, (80.64×)

Fig. 4-7 — 7-micron clad fibers, high contrast target



(a) Diffuse source illumination, 71.9 L/mm, (80.64×) (b) Point source illumination, 64 L/mm, (80.64×)

Fig. 4-8 — 7-micron clad fibers, low contrast target

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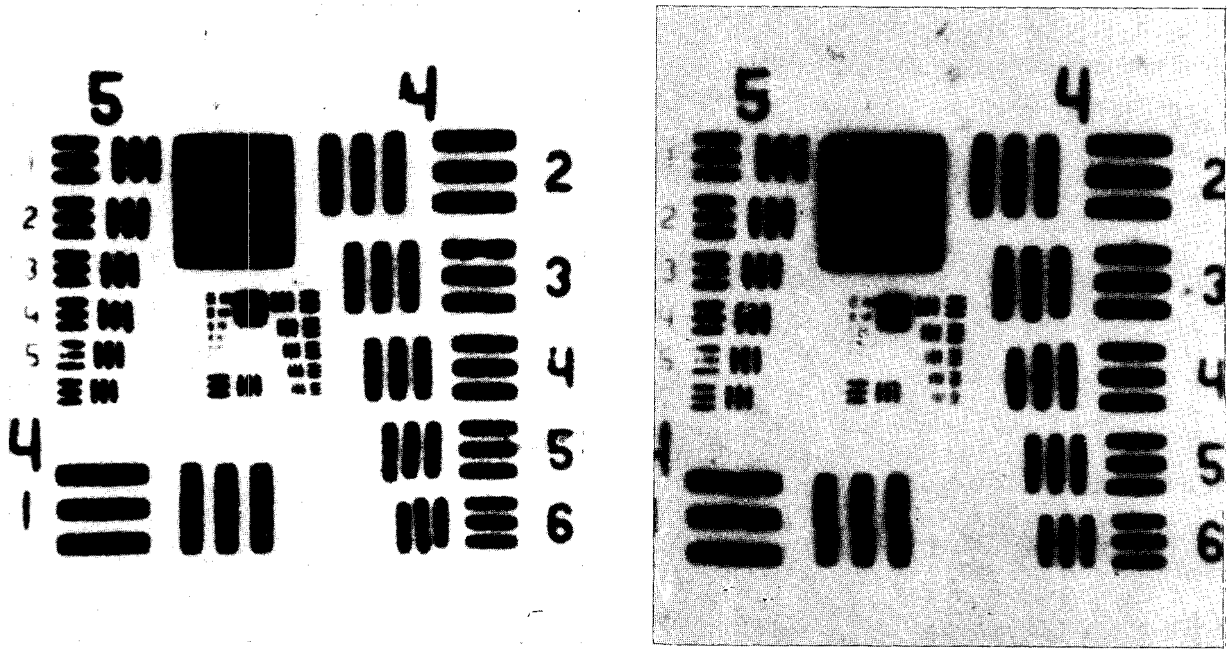
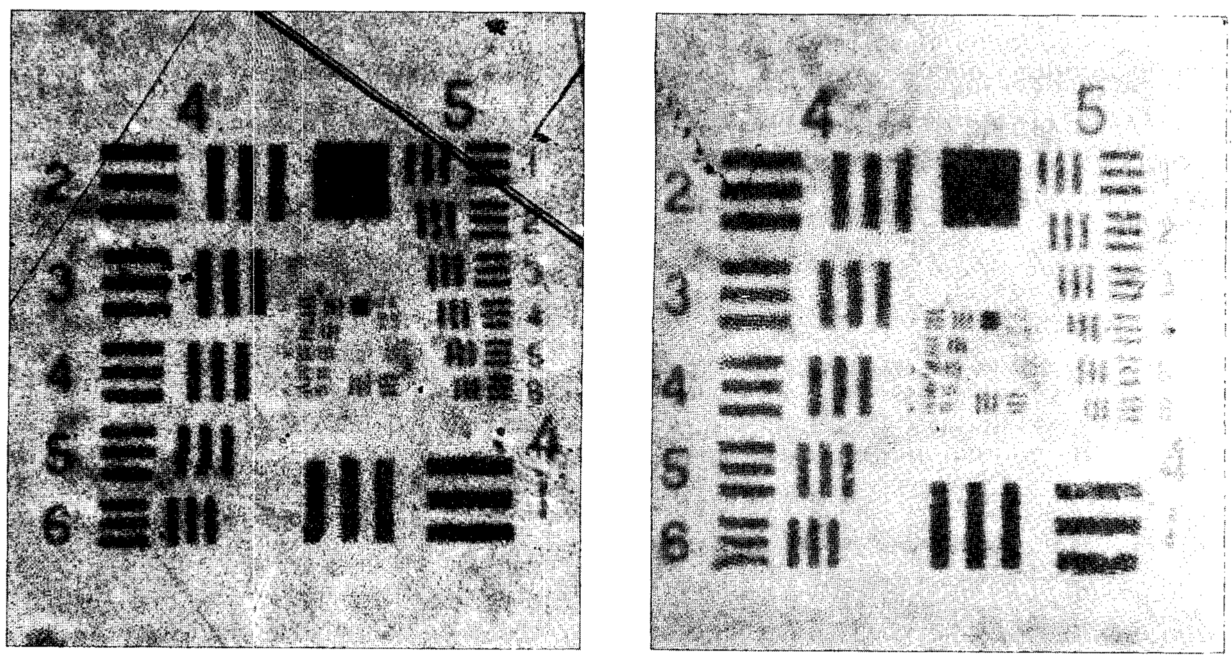


(a) Diffuse source illumination, 128 L/mm, (80.64×)

(b) Point source illumination, 102 L/mm, (80.64×)

Fig. 4-9 — 5-micron unclad fibers, high contrast target



(a) Diffuse source illumination, 80.7 L/mm, (80.64×)

(b) Point source illumination, 102 L/mm, (80.64×)

Fig. 4-10 — 5-micron unclad fibers, low contrast target

In addition to the previously described tests, another method was tried in an attempt to isolate stria caused by the fibers. This method involved the use of the previously described contact printer, used with its point source lamp. A Ronchi ruling (500 lines per inch), was used as negative material, and exposures were made both through the fibers and directly onto film. The processed negatives of each case were then superimposed, using inscribed index points. As one of the films was rotated, breaks in the S-shaped patterns were traceable to the fibers which indicated irregularities in transmission.

4.3 CONCLUSIONS

Every effort was made to determine just how much of the stria or the longitudinal banding was actually being caused by the fiber bundles. The results described herein deal with the actually apparent, stria or banding as can be attested by the attached figures. Dust or any other irregularity in the slit, can definitely cause density variations on film, and every effort was made to eliminate this source. In comparing films made with the fibers and with the slit alone, definite differences in density can be seen, which indicates that the fibers are a source of irregular transmission. This pattern repeated itself on successive tests, with the 7-micron fibers particularly presenting a pattern.

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5. TEST EQUIPMENT

In the course of conducting the spot size reduction study, several pieces of test equipment were designed and fabricated to facilitate system, and particularly resolution, evaluation. In this section, these test devices, mentioned in previous sections, are discussed in detail.

5.1 SWEPT FREQUENCY OSCILLATOR

As part of the program to measure recorder system resolution, a swept frequency oscillator (see Fig. 5-1) was developed to generate a linear fm sweep. The sweep can be adjusted to pass through zero frequency and up to 3,000 cps at rates varying from a fraction of a second to several seconds, with constant amplitude and with a high degree of sweep linearity.

The signal from this generator, when recorded, produces a pattern on film which is analogous to a Fresnel zone plate in one dimension. Analysis of this pattern through the use of the spatial frequency bench was helpful in determining the ultimate resolution of the recorder and also the existence of disturbances in the relative motion of the film and the CRT trace.

Circuit Description

The frequency sweep is generated with a multivibrator, Q4 and 5, 2N917's. The frequency of the multivibrator is varied linearly by a change in voltage applied to the collectors. The linearly changing voltage is supplied by Q1, 2N491, a unijunction ramp generator which drives Q3, 2N1231, through a capacitor. Clamping is provided in the base of Q3 to reestablish dc levels. The output of Q3 is applied to the collectors of the multivibrator Q4, 2N917, and Q5, 2N917, through potentiometer R13, frequency shift control. This potentiometer controls the excursion of frequency, nominally from 10 to 13 kilocycles of the multivibrator. A buffer amplifier, Q7 and Q8, both 2N1711, in a Darlington configuration couples the swept frequency output to the balanced mixer diode bridge CR6, CR7, CR8, and CR9. Here the signal is mixed with a fixed frequency of 10 kilocycles derived from Q2, 2N1889, fixed oscillator, and buffer amplifier, Q6, 2N698. The frequency of the fixed oscillator is adjusted by varying the inductance of L1. This is varied to place the zero beat of the output at the desired point in time. A blanking pulse derived from the unijunction ramp is applied in combination with the fixed oscillator output at point A to the base of Q6. The blanking amplitude is adjusted by R29. The combined blanking and fixed oscillator output of Q6, 2N698, is applied to the balanced bridge circuit through potentiometer R27, amplitude control, which controls the output level of the bridge. The output of the bridge is the difference in frequency between the fixed 10-kilocycle oscillator and the swept 10- to 13-kilocycle signal.

The balanced mixer circuit is unique in that no transformer is used. In an earlier version, several transformers were used in cascade but were found to create a phase error in the swept frequency output near zero frequency. This finalized circuit corrected the situation.

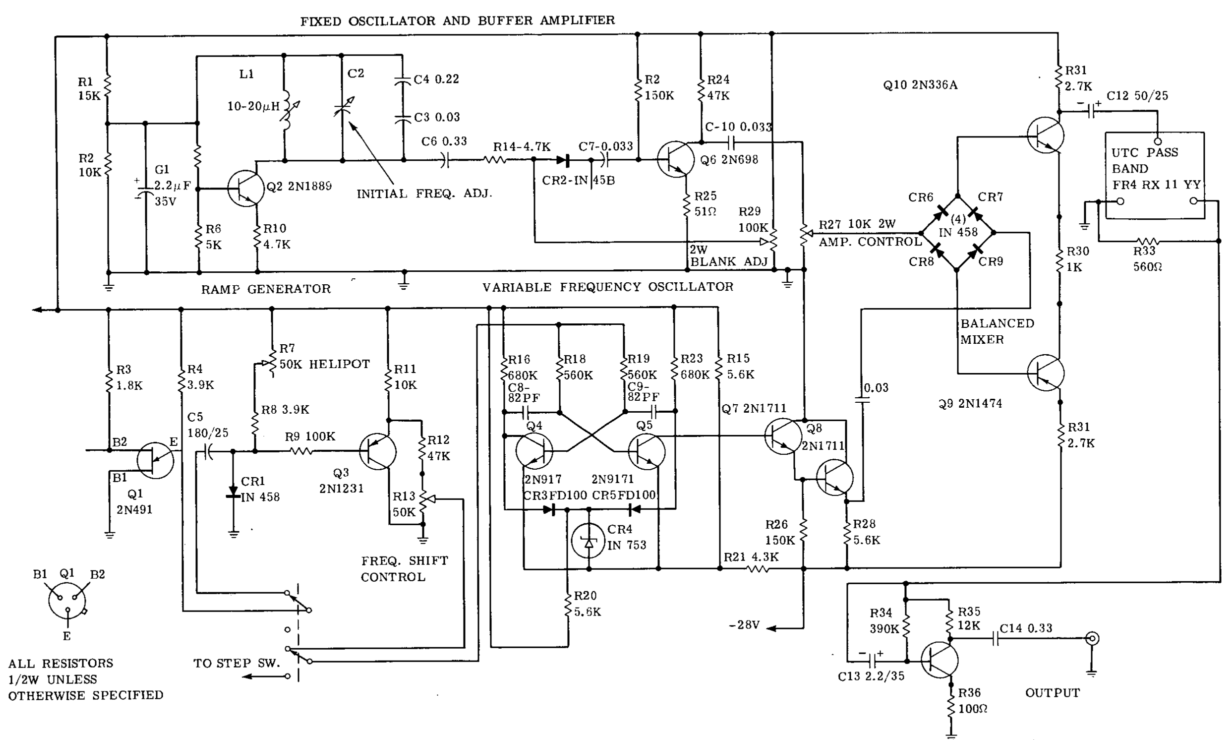

Fig. 5-1 — Circuit diagram of swept frequency oscillator

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The output of the diode bridge is coupled to a differential amplifier Q10, 2N336A, and Q9, 2N1474. Note that these are matched PNP and NPN transistors. The output is taken from the collector of Q10 and filtered by a low pass 0- to 4,000-cps filter. The filter drives Q8, 2N1711, the output stage of the unit.

An output of 20 volts peak to peak can be obtained from the unit. A further refinement recently incorporated in the unit is the inclusion of a stepping switch, mechanically driven, which supplies steps of voltage to the multivibrator, thereby causing the output to change frequency in step fashion. This switch can be switched in place of Q1, the ramp generator, and for certain types of analysis produces a more useful signal.

5.2 SLOW SWEEP TEST SET

A circuit was breadboarded which drove one of the 500-ohm centering coils on the yoke in a back and forth manner, producing a form of raster. The raster was made apparent by the combination of phosphor decay time and persistence of vision of the eye. The eye then "saw" (through the microscope) the line trace in the same manner that the film "saw" the trace. When a dot pattern was placed on the line trace on the CRT, the dots were spread across the CRT face to form a line pattern. Using this pattern, focus could be adjusted easily and disturbing hum fields readily discovered.

Since the circuit requires no external oscillator, it can be used as a convenient adjunct to the recorder as a piece of test gear to aid in adjusting for best electrical focus. Fig. 5-2 shows a block diagram of the circuit, while Fig. 5-3 shows the complete, detailed circuit. A unijunction pulse generator produces pulses every 0.3 to 0.05 millisecond, adjustable by the 20,000-ohm rate control. These pulses trigger the flip-flop (Q2, Q3) producing a square wave at the collector of Q3 having a half-period equal to the unijunction pulse rate. Common emitter inverter Q4 produces a clean square wave of about 30 volts amplitude which is ac coupled across R1 by C1. The ac coupling provides the symmetrical square waveform (no dc component) required at the input of the integrator R2 and C2. This RC combination shapes the wave into a series of exponentials. The complementary pair transistors Q5 and Q6 (NPN and PNP) serve as a symmetrical emitter follower, driving the 500-ohm centering coil in a bridge configuration. A balance potentiometer is added to the circuit to compensate for any differences in the PNP and NPN silicon transistors, since this is not a selected complementary pair, i.e., a PNP-NPN set with precisely matched characteristics. The balance control also serves as a method of positioning the trace so that it can be seen fully with a minimum of microscope adjustments.

The circuit can be packaged in a small aluminum minibox with binding posts to couple into the centering coil in the system. The required plus and minus 30 volts may be derived with zener diodes from the plus and minus 60 volts available in the system.

5.3 WHITE NOISE GENERATOR

A white noise generator (Figs. 5-4 and 5-5) was developed which covers the video spectrum from 1 kilocycle to 30 megacycles. In order to provide a more versatile piece of test equipment, the unit is divided into three independent chassis. These chassis are as follows:

1. A white noise source
2. A wideband video preamplifier
3. A portable, large signal video amplifier

The noise source is a selected zener diode, which can provide the requisite constant amplitude noise voltage into a 56-ohm load. The preamplifier is 3 db down beyond the 30 megacycles. The

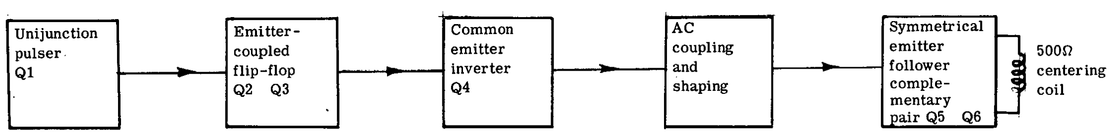

Fig. 5-2 — Block diagram of slow sweep test set

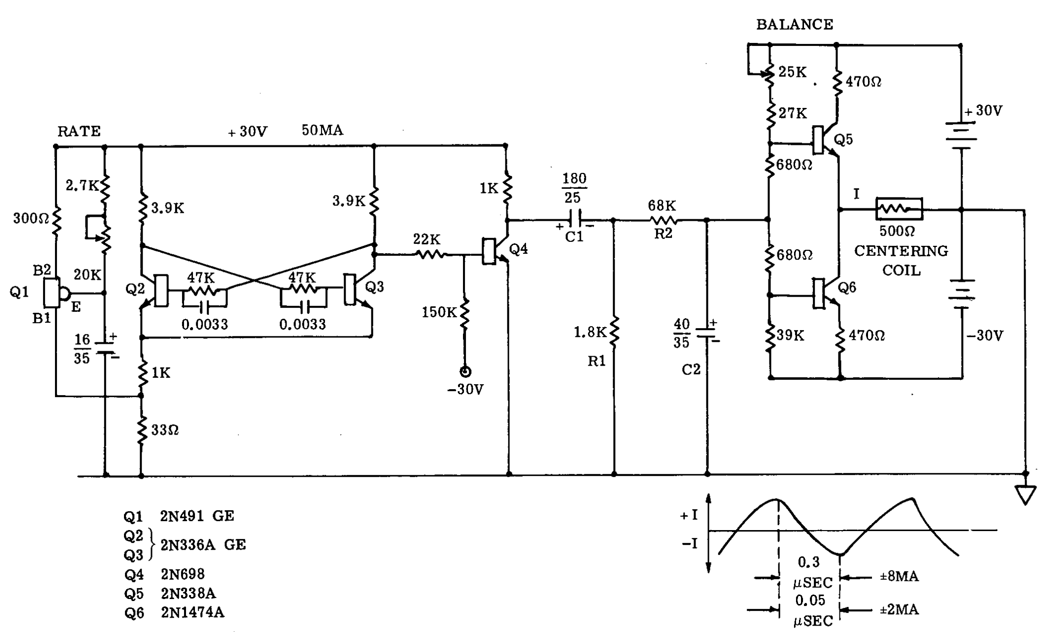

Fig. 5-3 — Circuit diagram of sl●w sweep test set

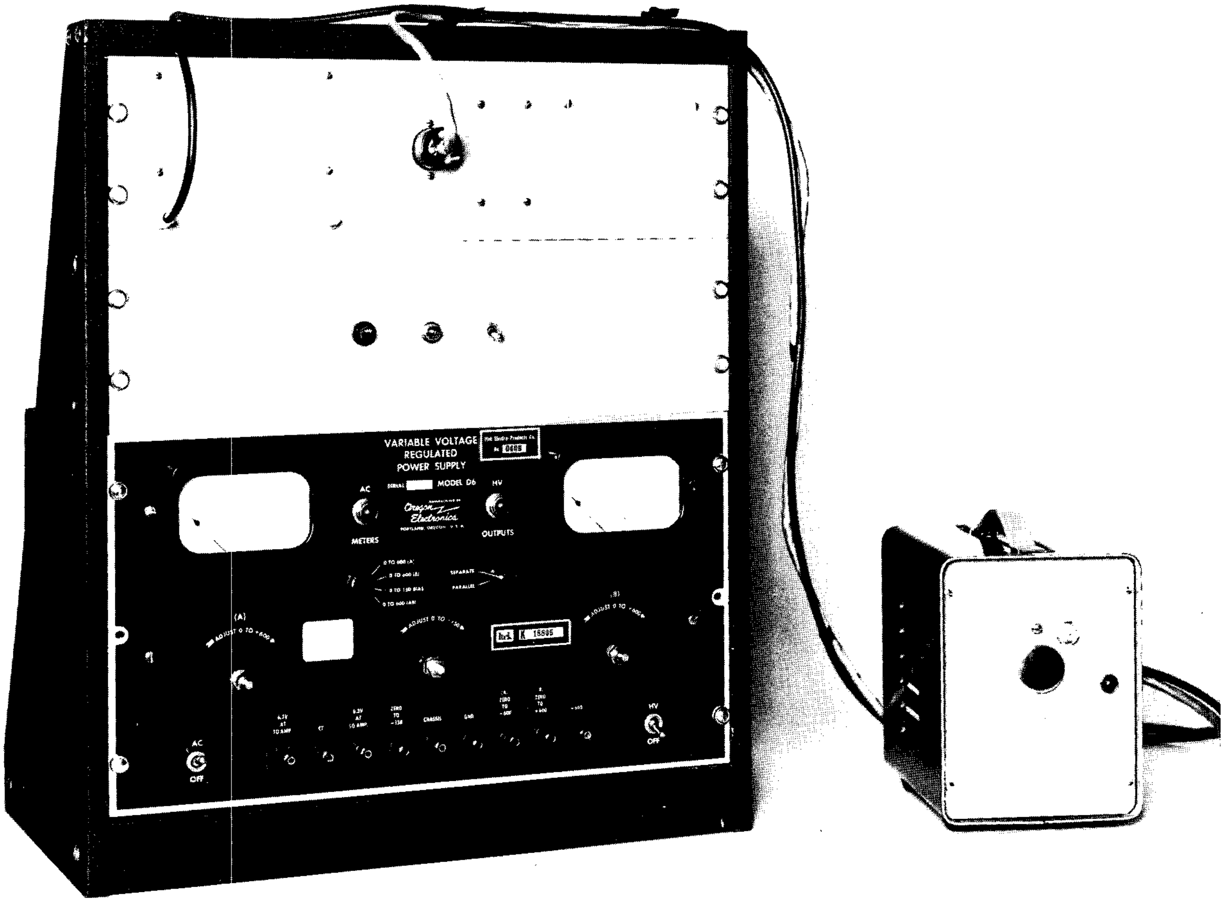

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Fig. 5-4 — Front view of white noise generator

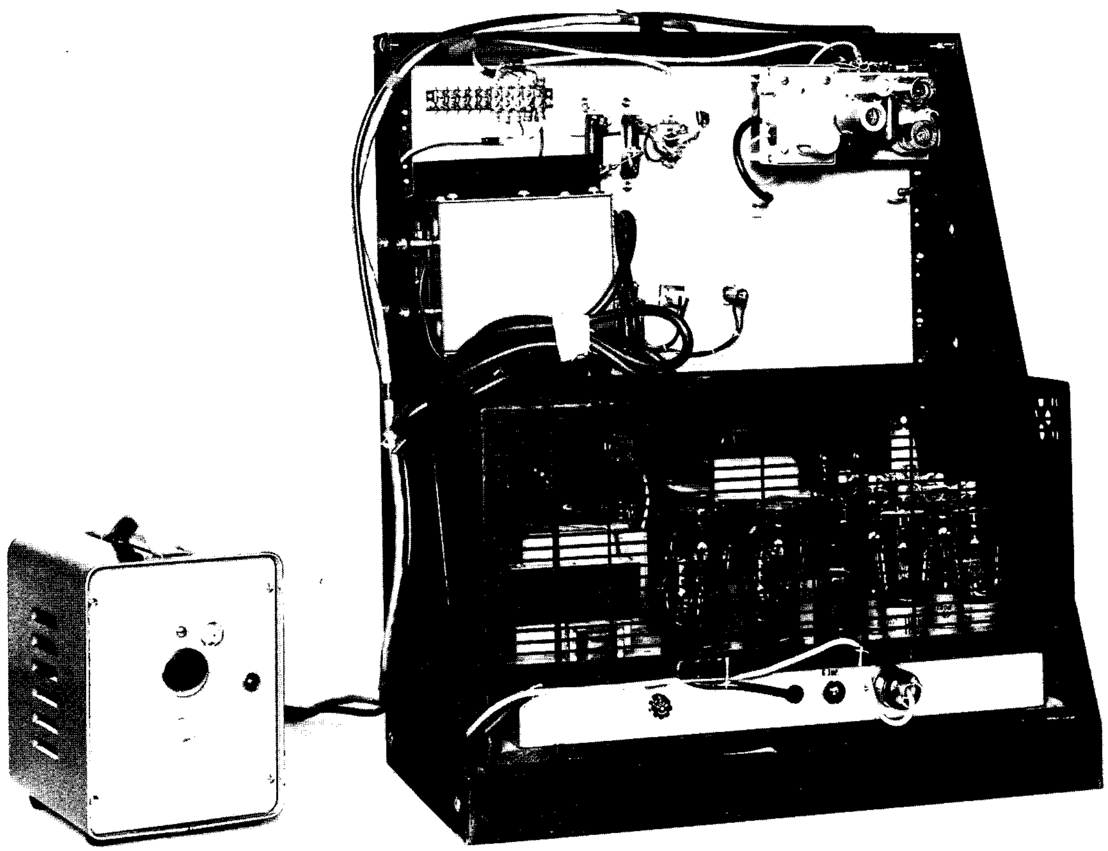

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Fig. 5-5 — Back view of white noise generator preamplifier can operate into a 91-ohm termination and provide a 40-db voltage gain. The final amplifier is down 3 db at 30 megacycles and is capable of a 23-db voltage gain. This amplifier provides a 30- to 40-volt peak to peak video signal into a 330-ohm plate load. Both amplifiers can pass a 1-kilocycle square wave with less than 10 percent tilt.

A system requirement for the recorder project was a white noise source encompassing the video spectrum from 1 kilocycle to 30 megacycles. The noise peaks had to be 30 to 40 volts to provide sufficient drive to the grid of the recording tube. A comprehensive search through various test equipment brochures indicated that the General Radio 1390-B random-noise generator satisfied a portion of the video spectrum requirements. This noise generator provides 1 volt output into a 900-ohm source impedance with a bandwidth of 500 kilocycles to 5 megacycles within ±8 db. This unit was purchased as general laboratory test equipment and preliminary system noise tests were run on the recorder with it.

Most noise sources have been designed for the low frequency spectrum (audio or even lower) or for the high frequency (communication or radar receivers) end. The available high frequency noise sources would have required rf amplification and wideband detection to achieve the requisite bandwidth. A wideband, large signal video amplifier would have been necessary to provide sufficient grid drive to the CRT.

Since there was no test equipment available with the requisite bandwidth and amplitude, a program was initiated to design and build a wideband, large amplitude, white noise generator.

5.4 NOISE SOURCE

Various components were evaluated for their capability of generating the required white noise spectrum with sufficient amplitude. The 6D4 gas tube was the first noise source investigated. A transverse magnetic field is necessary to produce noise from this tube. Large amplitude noise signals into a low value load resistor can be obtained from the tube, but the high frequency spectrum is limited (see Fig. 5-6).

Another noise source evaluated during this program was the temperature limited diode. The noise was masked by 60 cycles, which apparently could not be removed. The noise spikes had the appearance of pulses and were unidirectional.

Investigations of zener diodes as the noise source proved fruitful. Care has to be exercised in the selection of the zeners, insofar as they must have low shunt capacity. A Motorola high voltage 1/4M 100 Z5 zener diode having a low shunt capacitance provided the required frequency characteristics. This zener diode supplied approximately 2.0 millivolts rms into a 51-ohm load (see Fig. 5-7). The amplitude of the noise remained constant (within 3 db) beyond 25 megacycles. The white noise characteristics were measured using a panoramic spectrum analyzer. Fig. 5-6 demonstrates the response of the noise generated by the zener diode. The response was limited by the test equipment.

5.5 VIDEO AMPLIFIER

The video amplifier is a straightforward design, although there was a difficult requirement of providing to the grid of a CRT a large output voltage swing over a wide bandwidth (see Figs. 5-8 and 5-9).

5.6 PREAMPLIFIER

Amperex 7788 pentodes were used for the small signal video amplifiers in the preamplifier (see Fig. 5-10). These tubes have a transconductance of 50,000 microhms. The input shunt capacitance of the tube is high, which must be compensated for, and the output shunt capacitance is very low. This is an ideal tube to be used in wideband high gain, low signal video amplifiers. These tubes can provide high gain into low plate impedances. The tubes are microphonic and care must be exercised in mounting them to the chassis.

The filaments were heated by dc to minimize 60 cycle problems. In order to obtain the 30-megacycle bandwidth, care had to be exercised in the choice of decoupling and coupling capacitors. Care was employed in component layout to minimize lead length as well as lead dress, which permitted pushing the response beyond 30 megacycles.

5.7 LARGE SIGNAL AMPLIFIER

Since the 7788 pentode has (for large signals) a limited dynamic range, it was decided to use one Amperex tube for the intermediate amplifier and a 6BG6 as the final amplifier (see Fig. 5-11). This tube can accommodate large input signals and provide high output power. This design provides low impedance drive to the grid of the CRT.

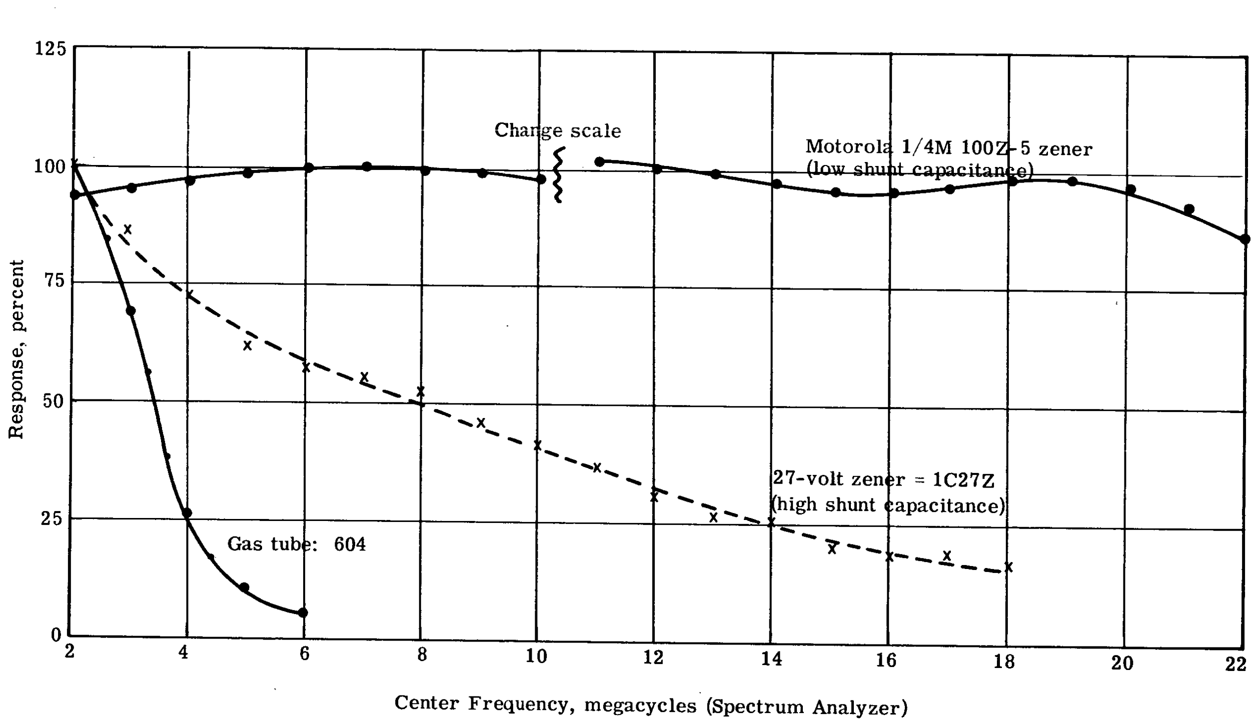

Fig. 5-6 — Noise spectrum of typical noise sources

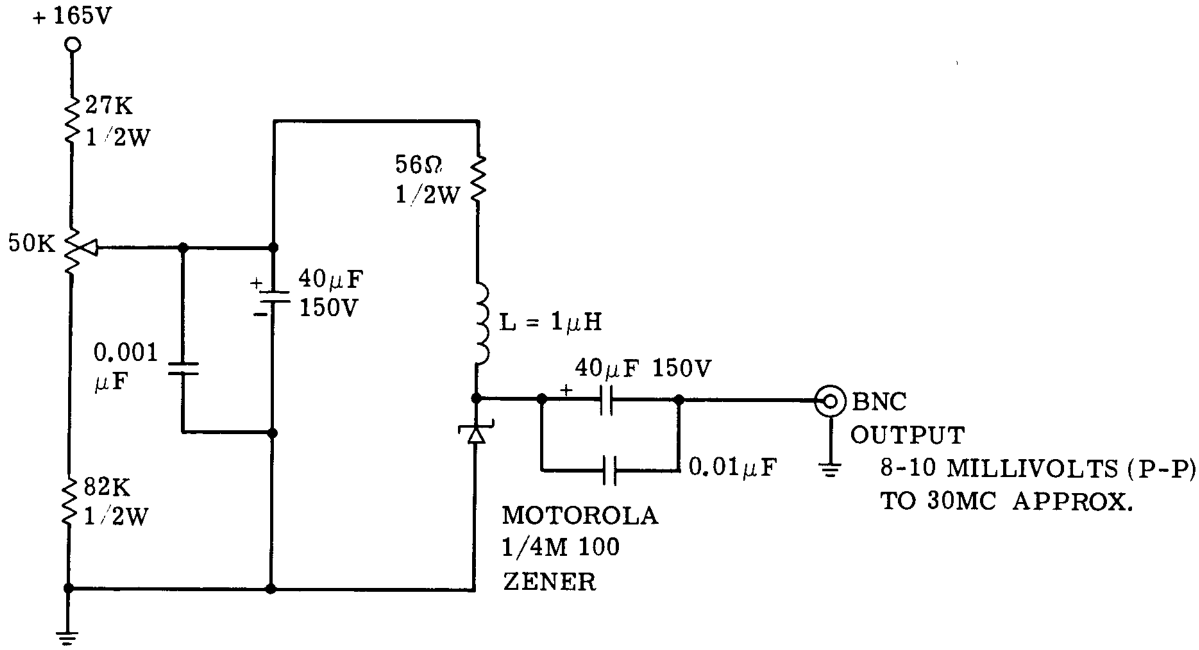

Fig. 5-7 — Wideband noise source

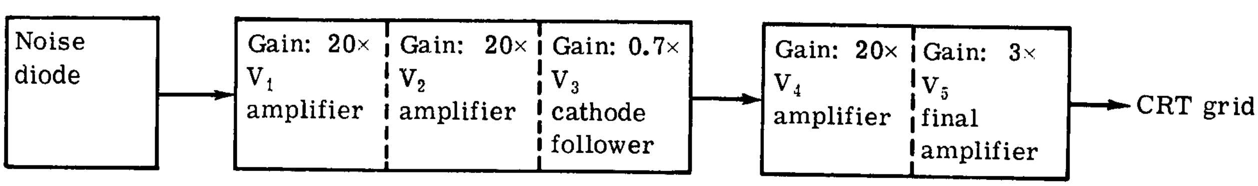

Fig. 5-8 — Simplified block diagram of white noise generator and wideband video amplifier

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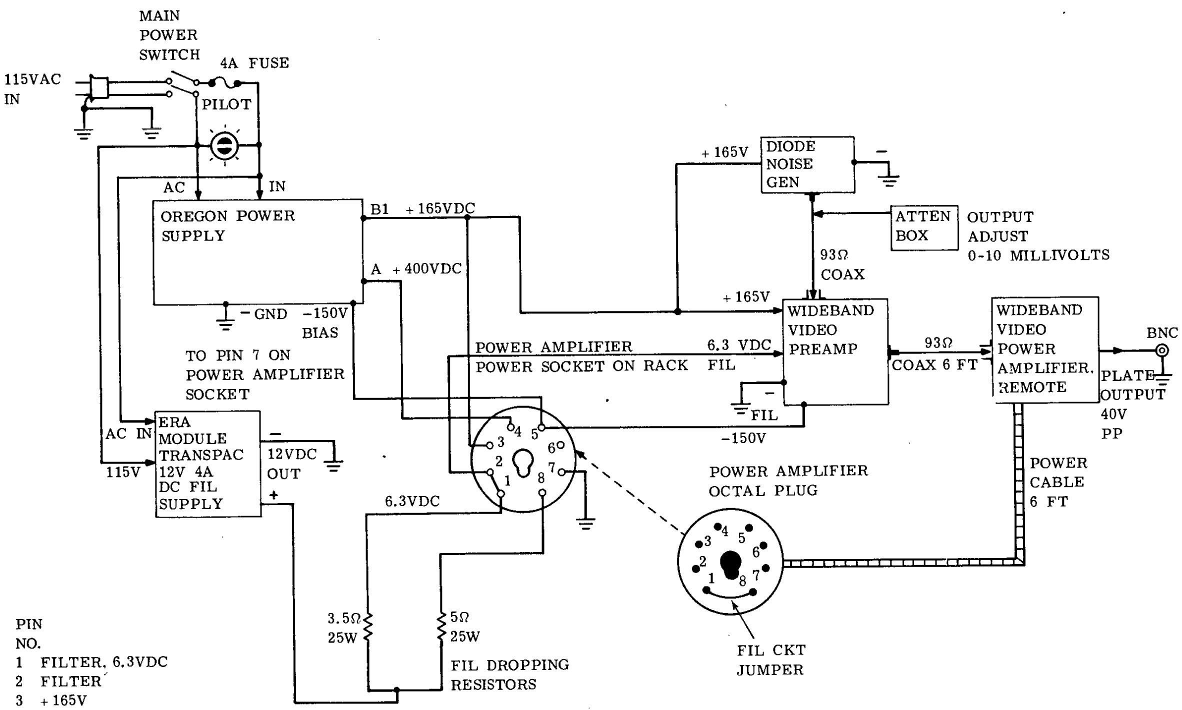

PIN NO.
1 FILTER, 6.3VDC
2 FILTER
3 +165V
4 +400
5 −150V
6 NO CONNECTION
7 GROUND
8 FILTER, 6.3VDC

Fig. 5-9 — Circuit diagram of noise generator, preamplifier, and amplifier

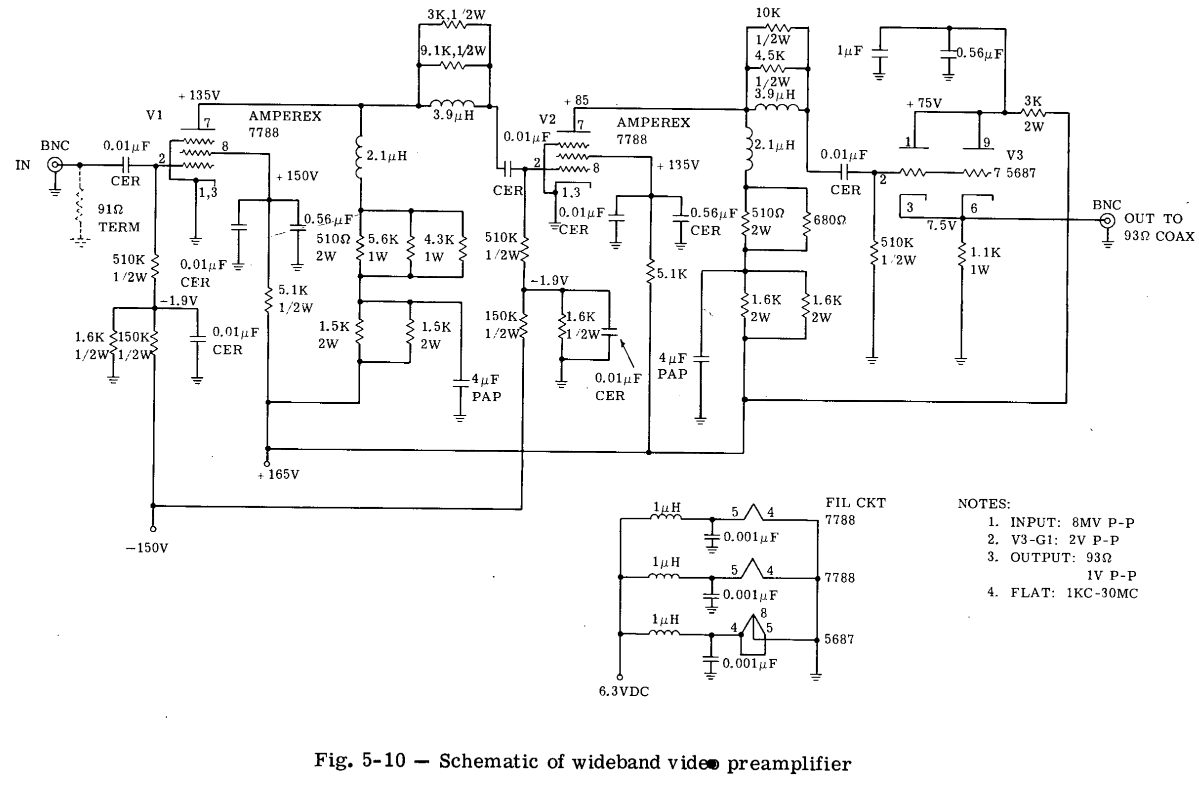

Fig. 5-10 — Schematic of wideband video preamplifier

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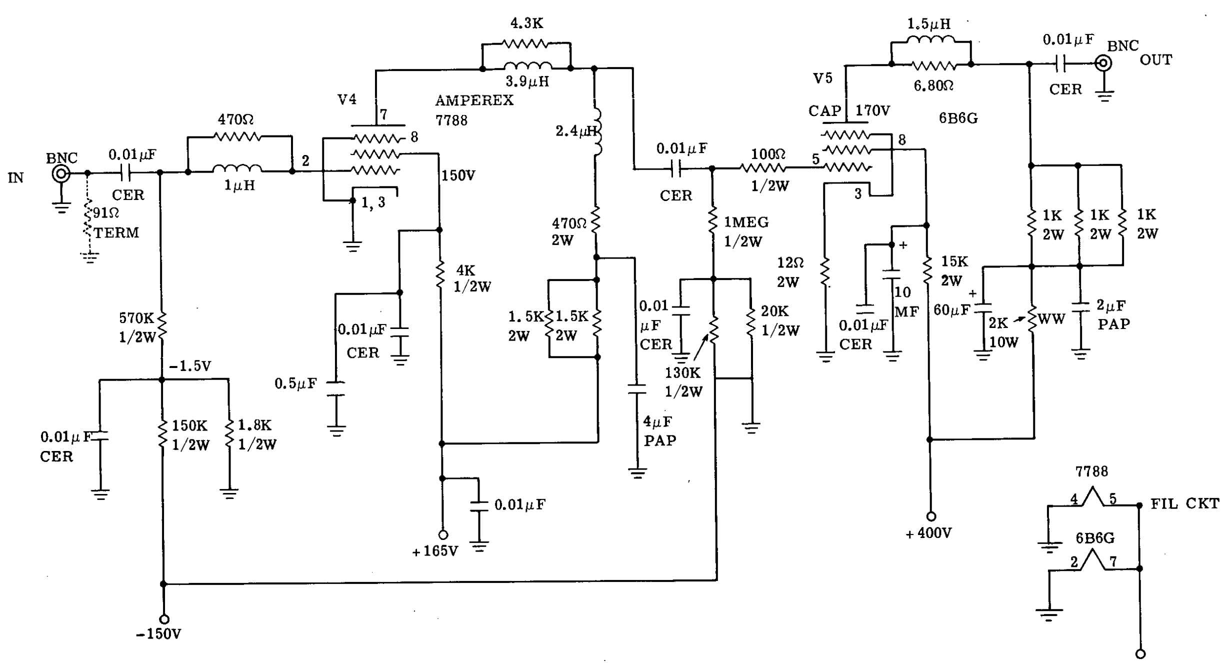

Fig. 5-11 — Schematic of wideband vide● output amplifier